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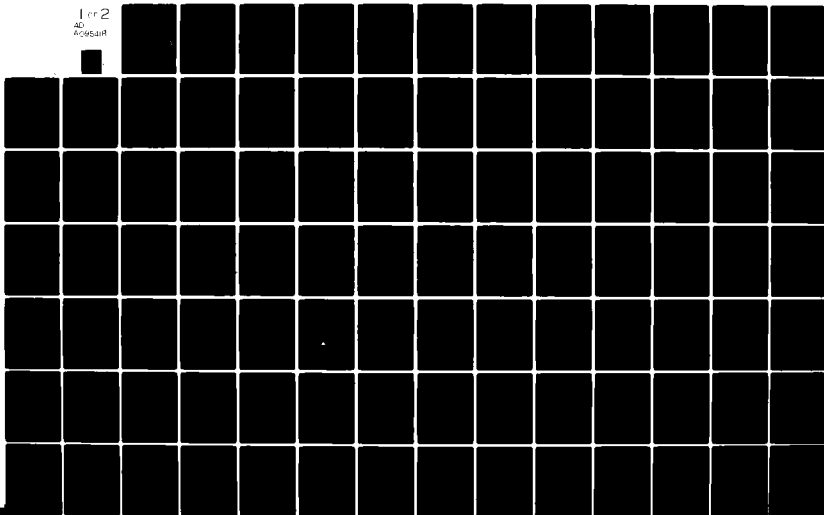
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| <p>The Issues of Commonality Study examines the significant institutional issues related to the acceptance of a concept for the development of a new large cargo aircraft. The proposed aircraft, referred to as the ACMA (Advanced Civil/Military Aircraft), nee C-XX is conceived as an advanced technology transport with the potential for fulfilling both the U.S. need for military airlift and the worldwide need for commercial airfreight in the 1990s and</p> | | |

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beoynd. There are many political and socio-economic considerations to be addressed when formulating a program involving government and industry participants with their particular and diverse interests. This study focuses on these interfaces and potential problem areas and examines four issues thought to be of more immediate concern to the successful initiation of a joint civilian/military venture.

These issues are:

- o Establishing the Commercial Need, U.S. and International
- o Development of a Financial Planning Concept
- o Energy Considerations that May Impact the Program
- o Impact of Engine Development/Acquisition

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ISSUES OF COMMONALITY STUDY

Volume II: ISSUE ANALYSIS

LG80ER0013

December 1980

Approved By: 

W. T. Mikolowsky, Manager

Engineering Systems Analysis Division

LOCKHEED-GEORGIA COMPANY

A Division of Lockheed Corporation, Marietta, Georgia

FOREWORD

The Issues of Commonality Study was performed by the Lockheed-Georgia Company for the Air Force Aeronautical Systems Division under contract F33615-78-C-0115. This final study report is presented in two volumes:

Volume I. Executive Summary

Volume II. Issue Analysis

The Air Force program manager was Dr. Larry W. Noggle. Mr. D. L. Bouquet was the Lockheed-Georgia manager for the initial study activities. He was succeeded by Mr. W. A. Garrett during the latter phase of the study.

Lockheed-Georgia personnel who participated in the Issues of Commonality Study include:

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TABLE OF CONTENTS

| <u>Section</u> | <u>Page</u> |
|--|-------------|
| FOREWORD | iii |
| LIST OF FIGURES | vii |
| LIST OF TABLES | xi |
| I. INTRODUCTION | 1 |
| Background | 1 |
| Tasks | 5 |
| Approach | 5 |
| Report Roadmap | 5 |
| A Summary Observation | 10 |
| II. ESTABLISHING THE COMMERCIAL NEED | 11 |
| Air Carrier Requirements | 11 |
| Cargo Market of the Future | 15 |
| Integrating the Commercial and Military Need | 17 |
| Summary of Findings | 18 |
| III. DEVELOPMENT OF A FINANCIAL PLANNING CONCEPT | 19 |
| Approach | 20 |
| Cooperative Ventures | 22 |
| System Development and Acquisition | 28 |
| Program Initiation Concept | 30 |
| Mission Element Need Statement | 30 |
| Representative Program Planning Schedule | 35 |
| Program Definition | 39 |
| Market Projection | 44 |
| System Definition | 47 |
| System Economics | 47 |
| Program Interrelationships | 51 |
| Representative Operational Program | 51 |
| Fleet Mix Concept | 54 |
| Financial Planning | 55 |

| <u>Section</u> | <u>Page</u> |
|---|-------------|
| IV. ENERGY CONSIDERATIONS THAT MAY IMPACT THE PROGRAM | 63 |
| Availability of Conventional Fuels | 63 |
| Aircraft Fuel Alternatives | 73 |
| Energy Considerations Relating to Engines for the 1990s | 77 |
| Energy Intensity Comparisons | 85 |
| Impact of a New Aircraft on Strategic Airlift | 89 |
| V. IMPACT OF ENGINE DEVELOPMENT/ACQUISITION | 93 |
| Performance Requirements | 93 |
| Cost of Ownership | 102 |
| Potential Engine Candidates | 103 |
| Timing of the Engine Program | 111 |
| VI. SUMMARY OF OBSERVATIONS AND RECOMMENDATIONS | 119 |
| The Commercial Need | 119 |
| Financial Plan | 120 |
| Energy Issue | 122 |
| Engine Issue | 123 |
| Recommendations | 124 |
| APPENDIX | 129 |
| GLOSSARY | 131 |
| REFERENCES | 135 |

LIST OF FIGURES

| <u>Number</u> | <u>Title</u> | <u>Page</u> |
|---------------|--|-------------|
| 1 | DoD Letter | 12 |
| 2 | DOT Letter | 13 |
| 3 | Free World Market Forecasts | 16 |
| 4 | Financial Planning Approach | 21 |
| 5 | Proposed National Air Cargo Fleet Act | 23 |
| 6 | Merchant Marine Act | 25 |
| 7 | Supersonic Transport Program | 26 |
| 8 | Communication Satellite Act of 1962 | 27 |
| 9 | Mission Element Need Statement | 31 |
| 10 | Proposed Commercial Need Statement | 33 |
| 11 | Program Initiation | 34 |
| 12 | Representative Program Planning Schedule | 37 |
| 13 | Military Need Derivation | 40 |
| 14 | C-141 and C-5 Phase Out | 42 |
| 15 | ACMA Equivalents | 42 |
| 16 | Civil Need Derivation | 45 |
| 17 | Market Projection and Market Shares | 46 |
| 18 | System Definition | 48 |
| 19 | System Economics | 50 |
| 20 | Influence of System Economics on Program Success | 50 |
| 21 | Program Interrelationships | 52 |

| <u>Number</u> | <u>Title</u> | <u>Page</u> |
|---------------|---|-------------|
| 22 | Representative Operational Program | 53 |
| 23 | Fleet Mix Concept | 56 |
| 24 | Representative Conceptual Phase | 58 |
| 25 | Representative Validation Phase | 60 |
| 26 | Representive Development Phase | 61 |
| 27 | Commercial Air Cargo and Military Strategic Airlift Petroleum Usage | 64 |
| 28 | Total U.S. Liquid Fuels Demand | 66 |
| 29 | A Typical Production Curve for a Non-Renewable Resource | 66 |
| 30 | U.S. Domestic Crude Oil Production Cycle | 67 |
| 31 | Comparative Energy Production Cycles | 67 |
| 32 | Forecast Consumption of Energy Products in the Transportation Sector, 1975 to 2000 Medium Growth Scenario | 71 |
| 33 | Specific Fuel Consumption Trends for Turbine Engines | 78 |
| 34 | Possible SFC Improvements with Increases in Cycle Pressure Ratio | 80 |
| 35 | Advanced Technology Propeller | 82 |
| 36 | Propulsive Efficiencies Possible with the Prop-Fan | 84 |
| 37 | Energy Intensities for All-Cargo Aircraft | 87 |
| 38 | Effects of Rising Prices on Operating Costs | 88 |
| 39 | Deployment Routes | 90 |
| 40 | Comparative Fuel Requirements for a Typical European Deployment | 91 |
| 41 | FAR 36 Stage 3 Noise Limits | 99 |

| <u>Number</u> | <u>Title</u> | <u>Page</u> |
|---------------|---|-------------|
| 42 | FAR 36 Noise Measuring Points | 100 |
| 43 | Estimated Influence of Advanced Technology on Turbofan and Turbo Shaft Specific Fuel Consumption | 108 |
| 44 | Estimated Influence of Advanced Technology on Turbofan and Turboshift Engine Weight | 109 |
| 45 | Representative Transport Engine Development (Military) | 114 |
| 46 | Representative Transport Engine Development (Commercial) | 116 |
| 47 | Representative Derivative Engine Program | 117 |
| 48 | Recommendations | 125 |

LIST OF TABLES

| <u>Number</u> | | <u>Page</u> |
|---------------|--|-------------|
| 1 | Government/Industry Contacts | 6 |
| 2 | Growth in the Demand for Transportation Fuels | 70 |
| 3 | Properties of Candidate Fuels | 74 |
| 4 | Energy Intensity by Transportation Mode | 85 |
| 5 | Fort Hood to Frankfurt Deployment Summary | 89 |
| 6 | 1973 Middle East War Resupply Effort | 92 |
| 7 | Evaluation of Approximate Required Turbofan Engine Size | 95 |
| 8 | Engine Size Range - Propeller Powerplant | 96 |
| 9 | The Fuel Economy Picture | 98 |
| 10 | The Transport Engine Picture: 1980 - 2000 | 104 |
| 11 | Commercial and Military Procurement Decision Differences | 113 |
| 12 | Issue Listing | 130 |

I. INTRODUCTION

Since 1974, when the Military Airlift Command proposed the concept of commonality between civil and military transport airplanes, the Air Force has sponsored various studies on the technical feasibility, cost effectiveness, and design trade-offs for a large, advanced technology, transport aircraft. Originally designated C-XX, but now known as the ACMA (Advanced Civil/Military Aircraft), such aircraft would have the potential to meet not only the strategic military airlift needs of the United States at reduced investment, operating, and support costs; but would also provide the world-wide civilian cargo industry with more efficient airfreight capabilities. (The terms "civil" and "commercial" are used interchangeably and in their broadest sense to include U.S. domestic and international carriers as well as other international carriers of the free world.)

There are many important institutional issues related to the acceptance of a joint civil/military development concept due to the numerous and significant interactions between government (both military and domestic agencies), in industry (both manufacturers and air carriers), and international aviation interests. These interactions, and the potential conflicts, are the central focus of the Issues of Commonality Study. This report summarizes the work performed to date by Lockheed-Georgia on the Issues of Commonality Study for the Aeronautical Systems Division, Deputy for Development Planning, Air Force Systems Command.

In this introductory section we present the background for, the specific tasks, the approach used and a roadmap of the study. The in-depth examination of four selected issues is presented in Sections II, III, IV, and V, respectively. A summary of findings is presented in Section VI.

BACKGROUND

The concept of a joint civil/military cargo aircraft development program to satisfy both commercial and national needs has been advocated for a number of years as evidenced by the following events and comments:

- o In March 1959, FAA Administrator Edward R. Quesada proposed a government-funded program for the development of an "uncompromised" cargo aircraft. Legislation for such an initiative was introduced by Senator A.S. (Mike) Monroney, Chairman of the Senate Commerce Aviation subcommittee. Senator Stuart Symington was co-sponsor.
- o In May 1973, Mr. Robert Prescott, President of Flying Tigers Airlines, in his acceptance speech as the NDTA "Man-of-the-Year," outlined the need for a joint civilian and military air cargo transport development program and called for "... a plane designed as a cargo aircraft from the ground up."
- o In February 1974, the Military Airlift Command (MAC) published a military concept for an advanced cargo transport aircraft, designated as the C-XX, designed to augment strategic military airlift forces and as a Civil Reserve Air Fleet (CRAF) resource (Reference 1).
- o Major General Fred Starr, Jr., Director of Transportation, Headquarters U.S. Air Force, in a presentation before a NASA Air Cargo Workshop in February 1976, strongly advocated "a joint government/industry endeavor to design, develop, and manufacture an all cargo aircraft with potential benefits to both industry and defense needs. Government and industry should be thinking in terms which view civil and military airlift as a total package; a comprehensive, complementary and mutually supporting arrangement."
- o In testimony before the Sub-Committee on Research and Technology, House Armed Services Committee in November 1976, Mr. Robert Hage, Executive Vice-President of the Douglas Company, McDonnell Douglas Corporation, cited the need for "the government and civil agencies to explore and endorse the concept of development of super air freighters."
- o In July 1976, the Aeronautical Systems Division, Air Force Systems Command, initiated a series of contractual studies to examine the commercial-military commonality issues to determine the feasibility of

designing a new air freighter aircraft to satisfy the needs of both the commercial market and the military logistics mission (Reference 2).

- o General P. K. Carlton, Commander MAC, noted in a speech to the St. Louis Traffic Club in January 1977, "the wasteful imbalance of passenger and cargo capacity in the civil fleet which could be corrected by development of an aircraft designed cooperatively by military and civil interests as a pure airfreighter."
- o In April 1977, a Task Force established by the Military Airlift Committee of the National Defense Transportation Association, published a report of findings pertaining to their assessment of potential public interest in the U.S. Government and U.S. Industry providing funds and other support towards the development of a new generation of cargo-capable aircraft with both military and commercial application (Reference 3).
- o The Deputy Secretary of Defense, in a letter to the Secretary of Transportation dated 26 April 1979, cited DoD "support for the serious examination of joint civilian/military aircraft developments" and solicited assistance in undertaking cooperative evaluations.
- o On 24 May 1979, the Secretary of Transportation sent a letter to the Deputy Secretary of Defense, "heartily" endorsing the concept for inter-agency evaluation of possible civil/military cooperative airlift developments and stated that "there is no question that in this time of increasing costs and declining resources we need to make the best possible use of our nation's developmental effort to achieve the most efficient and economic military and civilian transportation systems."
- o In recognition of the military need for additional strategic airlift, the Military Airlift Command (MAC) issued a Statement of Need (SON) in August 1979, for a new intertheater airlift vehicle (Reference 4).

- o In March 1980, in a preliminary report examining the various factors that could impact the future evolution of air cargo transport, the Office of Technology Assessment (OTA) concluded that although there are several cargo aircraft development program variants possible, the logic and potential economies of a joint civil/military program justify further evaluation (Reference 5).
- o In January 1980, based on the assessment provided in the MAC Statement of Need, Air Force Headquarters confirmed the validity of the ACMA concept and requested MAC to prepare a more detailed Basis of Need for "a new airlift aircraft which is both militarily productive and commercially competitive ... as a replacement for the C-5 by the year 2000" (Reference 6).
- o As a follow-up to their 1977 report on a joint program, the MAC Task Force has been investigating the possibility of securing passage of a National Airlift Expansion Act, to "ensure Government and civil progress toward a more meaningful partnership" (Reference 7).

In addition, attempts have been made in the past to develop a common transport aircraft intended for use by both civil and military operators.

- o The C-141 aircraft was certificated under civil air-worthiness standards set by the Federal Aviation Agency (FAA), but was never sold to a commercial carrier.
- o The C-5, which was designed to the more stringent of the Federal Air Regulations or military specifications, was a certificatable aircraft with some minor modifications.

The military's past unwillingness to incorporate economically attractive commercial design compromises into the C-5 and C-141 was the major obstacle to any of these earlier common transport aircraft programs.

TASKS

To accomplish the objective of this study, our first task entailed a comparative study of both commercial and military system acquisition processes and the definition and preliminary examination of the many non-technical functional issues relevant to the final acceptance of the commonality concept. The results of these preliminary studies (Phase I) were reviewed by the Air Force project engineer and his selection of six of the issues for a more detailed analysis provided the second task (Phase II). The Appendix to this volume summarizes the Phase I study and lists of the 16 preliminary issues. As suggested by the Air Force project engineer, the six selected issues were combined into four. These are: Establishment of Commercial Need, U.S. and International; Development of a Financial Planning Concept; Energy Considerations that May Impact the Program; and the Impact of Engine Development/Acquisition on the Program.

APPROACH

In conducting this study, opinions and advice were solicited from a cross-section of senior executives within the government and aviation industry. The principle offices contacted are listed in Table 1.

Each of the issue analyses in this study depended heavily upon the expertise of senior executives who represent specific interests in over 65 offices in the airlines, the military, and the various government agencies.

REPORT ROADMAP

A listing of 16 significant issues identified during Phase I are provided in the appendix. After review by the Air Force project manager the following six issues were selected for more in-depth study during the remainder of our study effort:

- o The establishment of the commercial need.
- o The development of a financial planning concept for the development, acquisition, and operation of the system including the basis for recoupment of federally funded R&D costs.

TABLE 1
GOVERNMENT/INDUSTRY CONTACTS

| <u>FEDERAL GOVERNMENT</u> | |
|--|--|
| <ul style="list-style-type: none"> ● Office of Federal Procurement Policy/OMB ● Department of Defense <ul style="list-style-type: none"> - Office of Secretary of Defense - Joint Staff, Joint Chiefs of Staff - Air Staff, Headquarters U.S. Air Force - Military Airlift Command - Aeronautical Systems Division, Air Force Systems Command ● Department of Transportation <ul style="list-style-type: none"> - Research & Special Programs - Transportation Systems Center - Federal Aviation Agency ● NASA Headquarters <ul style="list-style-type: none"> - Langley Research Center ● Legislative Branch | |
| <u>STATE/COUNTY GOVERNMENT</u> | |
| <ul style="list-style-type: none"> ● Hartsfield International Airport, Atlanta, Georgia ● Dade County Planning Commission, Miami, Florida | |
| <u>INDUSTRY</u> | |
| <ul style="list-style-type: none"> ● American ● Continental ● Delta ● Eastern ● Flying Tigers ● Northwest Orient | <ul style="list-style-type: none"> ● Pan American ● Seaboard World ● TransAmerica ● Trans World ● United ● World Airways |

- o Energy considerations that may impact the program.
- o NATO participation.
- o Foreign commercial sales.
- o Is engine development/acquisition program a pacing factor?

At his suggestion we combined these into four priority issues for more detailed analysis in the final phase of our study. The following is an overview of these four issues.

The Commercial Need

Since the commercial need is primarily driven by the potential profitability of an advanced technology aircraft, in anticipation of a growing cargo market, the initiation of a joint development program is, in large part, dependent upon the establishment of reliable cargo market forecasts that will justify civil acquisition and operation of such an airfreighter in the post-1990 time period. A comprehensive development program that substantiates the U.S. and International commercial market while integrating the particular requirements of the civil and military operators is, therefore, essential to the commonality concept.

In Section II, specific commercial concerns are addressed and an analysis of the future commercial market is made. Although only domestic air carriers were contacted by personal visit, we did solicit the opinion and advice of foreign air carriers as well. As noted, these carriers expressed a high degree of interest in the development and operation of an advanced technology air cargo system.

The Financial Plan

Issues pertaining to the formulation of a financial planning concept for the development, acquisition, and operation of an advanced cargo transportation system designed to satisfy large volume commercial cargo needs and emergency military airlift requirements are considered in Section III of this report.

This issue is perhaps one of the most subjective and complex of the many problems inherent in a civil/military aircraft development program because of the diverse financial arrangements and the implied management interfaces involved when considering domestic and foreign carriers and the associated political interests. In addition, the concept of a cooperative government/industry venture of this scope is without comparable precedent. A summary review and assessment of four previous financing approaches are, however examined for their relevance.

The financial plan we discuss in Section III is structured around three phases: the conceptual phase, the validation phase, and the development phase. Each of the three is patterned after government procurement policies and is explored in detail including a description of the action required, the agencies and organizations most capable of taking the action, and funding concepts for each phase. In addition, some implications of a projected production program are briefly discussed.

Primary input into this issue analysis came from air carriers, government agencies, and Lockheed financial advisors. Our basic approach was to solicit the opinions of these executives in the financial arena and document the various funding decision milestones and decision paths, then postulate the alternative financial arrangements applicable to the various acquisition phases of a potential joint program.

Energy Considerations

Since energy is a major international issue today, the question arises as to how energy considerations will affect a joint civil/military aircraft program. This problem might be restated as follows: Will it be in the public interest to develop a new air cargo transportation system for the 1990s in view of ascending fuel prices and diminishing domestic supplies?

In Section IV, several aspects of this energy problem are examined and a brief discussion of future fuel availability is presented. Among the areas covered are:

- o Availability of conventional fuels
- o Aircraft fuel alternatives
- o Energy considerations related to engines
- o Energy savings for commercial air cargo
- o Impact of a new aircraft on strategic airlift

In our examination of energy considerations we made an intensive literature search and consulted personally with responsible officials within the Federal Government and the private sector. Data was obtained from the Departments of Transportation, Energy, and Commerce. Geological survey forecasts for energy supply and demand through the end of the century were also used. Similar literature searches were conducted to establish a basis for examining the potential availability of alternative fuels and future engines. Once we had established a data base, key people within the Department of Energy, the Federal Aviation Agency, and the airline and petroleum industry were personally interviewed. These contacts prompted further research and provided additional perspectives into the issues.

The Engine Issue

There are a number of key, non-technical and technical considerations that will bear on the question, "Is engine development/acquisition program a pacing factor?" Some of these non-technical and technical influences are:

- o How to coordinate the differences in commercial and military procurement procedures.
- o What type of financing will be available?
- o What is the required engine thrust or horsepower?
- o How much will energy efficiency improvements pay off?
- o What are the impacts of design on operating economy (materials, number of parts, maintainability)?
- o Are satisfactory derivatives of current engines going to be available?
- o What are the requirements for new technology to permit improved energy efficiency and reduced operating costs?

In Section V, these non-technical and technical influences are evaluated in a generally qualitative manner since it is beyond the scope of this assessment to consider a specific airplane preliminary design or a specific engine development program. Engine manufacturers were contacted for their advice and opinions.

A SUMMARY OBSERVATION

We wish to note that almost without exception, the concept of a government/industry cooperative development program has stimulated the imagination of all those we contacted. While there have been a few skeptics, the overwhelming majority hold the view that the successful initiation of such a program represents a challenging, yet attainable goal. We believe this study provides valuable insight into several of the many and complex factors influencing the initiation of such a program.

II. ESTABLISHING THE COMMERCIAL NEED

Acceptance of a civil/military cooperative airlift development concept has been evidenced at the highest government levels as seen in Figures 1 and 2. However, the viability of a joint civil/military transport program must involve participation by U.S. and International carriers. Their participation will be motivated by the common economic necessity for acquiring and operating advanced-technology aircraft in anticipation of a growing cargo market. To date, there has been no widely accepted world-wide cargo flow projections that assume the availability of, and the concomitant market enhancement of an advanced technology transport aircraft. In our investigation, we surveyed the carriers' market projections, as well as projections made by Lockheed, NASA, and the DOT Transportation System Center at Cambridge, Massachusetts, to arrive at a consensus of cargo market growth in the time frame of interest (1990-2010). A substantial commercial market for a long-range aircraft with payload capability greater than presently available was projected by the recent NASA-sponsored Cargo/Logistics Systems Study (CLASS) (References 8 and 9). This section includes a discussion of the various aircraft requirements expressed by the civilian operators we contacted, and an analysis of the future commercial cargo market. We conclude with a brief discussion of how the integration of commercial and military needs might best be achieved.

Because "Establishing the Commercial Need" is an issue that impacts heavily on the "Development of a Financial Planning Concept" issue, commercial need is further addressed in Section III.

AIR CARRIER REQUIREMENTS

Air carrier requirements are discussed below in terms of aircraft size, program timing, ground facilities, and cruise speed.

Size

The majority of airline representatives contacted favor a new cargo aircraft; they differ however on the size aircraft required. Carriers with long-range



THE DEPUTY SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301

APR 26 1979

Honorable Brock Adams
Secretary of Transportation
Washington, D.C. 20530

Dear Mr. Secretary:

For the past several years, a partnership has been discussed between government and industry in meeting increased needs for civilian and military air transportation. Although future growth patterns in the commercial cargo market seem uncertain, we still support the serious examination of joint civilian/military aircraft development.

We already have some experience that verifies our conclusion. "NIFTY NUGGET," our recent mobilization exercise, demonstrated that the military is becoming increasingly dependent upon civilian airlift capabilities in order to meet defense airlift needs. By increasing the number of aircraft convertible from civilian to military use, the Civil Reserve Air Fleet (CRAF) demonstrates that civilian/military cooperation can help to develop a cost-effective and flexible national airlift capability. Additionally, we expect that our new program to modify wide-bodied passenger aircraft for defense use will establish a foundation for further cooperation in reducing the development costs of engines and air cargo systems.

Improvement in transportation efficiency and flexibility is essential both to our economy and to our national security. In a time governed by increasing costs and diminishing resources, improvements must be explored cooperatively. We ask your department to join with us, NASA, the Department of Justice, and the Department of Energy to evaluate civilian/military cooperative airlift developments. We would appreciate your designating a Department of Transportation point-of-contact to participate in this initial cooperative evaluation.

Sincerely,

Figure 1. DOD Letter



THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

510 MAY 25 AM 11:21
OFFICE OF
THE SECRETARY OF DEFENSE

MAY 24

Honorable C. W. Duncan, Jr.
Deputy Secretary of Defense
Washington, D.C. 20301

Dear Mr. Duncan:

Thank you for your letter of April 26 inviting us to join with you and others in a program to evaluate possible civilian/military cooperative airlift developments. I heartily endorse such an effort and I commend you for initiating the idea. There is no question that in this time of increasing costs and declining resources we need to make the best possible use of our Nation's developmental efforts to achieve the most efficient and economic military and civilian transportation systems. The program you suggest could lead to better future systems and also aid in hastening their development.

I am designating Mr. John Wesler, Acting Associate Administrator for Policy and International Aviation Affairs for the Federal Aviation Administration, as the primary point-of-contact for the Department of Transportation. He will keep me apprised of the program and how we can best help its advancement.

I appreciate your taking time to share your views with me.

Sincerely,

Brock Adams

Figure 2. DOT Letter

domestic and overseas routes see the primary need as a large transport aircraft with a payload capacity considerably larger than the 747F. Those carriers currently operating over short-haul domestic routes are interested in a smaller aircraft. Still another sector of the commercial carriers prefers a passenger-cargo configuration. The payload requirements discussed by the airlines can be summarized as follows:

| | |
|----------------|----------------------|
| Small Payload | 40,000 - 60,000 lb |
| Medium Payload | 100,000 - 120,000 lb |
| Large Payload | 300,000 - 400,000 lb |

Timing

Opinions of the airline representatives indicate that the timing of the commercial need for these aircraft varies from the late 1980s to the middle 1990s depending upon the individual carrier's projected fleet age and anticipated share of the projected market. Although none of the carriers surveyed had completed an in-depth marketing study of the world-wide cargo requirements for the 1990s and beyond, some did foresee an initial world-wide need for 50 to 125 large-payload aircraft for the time frame under consideration.

Ground Facilities

Several airline representatives contacted expressed concern over the relative inefficiencies in present methods of cargo handling and the air/ground interface operation. They stressed the need for early studies of the overall cargo handling problem and, in particular, any potential penalties of efficient commercial operations which may result from the incorporation of military features that have little or no significance in commercial use.

Cruise Speed

The requirement for high cruise speeds appears to be of secondary importance to many of the carriers, and indeed much more interest is being placed on the potential economics of lower cruise speeds because of spiraling fuel costs. There is uniform opinion however, that whatever the cruise speed decided upon,

it should be compatible with other existing aircraft at the same cruise altitude. The type engine is related to the cruise speed; and though the turbofan/profan engines promise improved Direct Operating Costs (DOCs), the carriers tend to favor an advanced turbofan with improved fuel consumption characteristics.

CARGO MARKET OF THE FUTURE

The airline representatives consulted during the course of this study stressed the need for an in-depth, unbiased market analysis to establish a valid basis for projecting commercial needs into the 1990s. Various aircraft manufacturers, airlines—both domestic and foreign, and other organizations with varying degrees of vested interest have made projections of the future cargo market. Since these forecasts vary considerably over the time period of interest (some span only the next two to three years, while others extrapolate to the year 2000), Lockheed developed a more extended market forecast for this study. The earlier forecasts also varied in assumption and forecasting techniques which further compounded our difficulty in correlating the results. Our projection techniques and market forecast are discussed in detail in Section III.

Figure 3 is a compilation of some of these forecasts. While we do not intend that "the" market forecast can evolve from the data in Figure 3, we do believe their combined trends can be evaluated as a plausible envelope of forecasts that could be helpful in postulating the maximum and minimum number of airplanes required. These requirements are represented by the shaded area in Figure 3. The difference in the individual forecasts for 1980 of over 100 airplanes is a result of the forecasts having different base years.

If it can be shown, albeit simplistically, that even the minimum forecast requirement for aircraft is large enough to establish a reasonable initial production base, then the civil endorsement of the joint program and the early initiation of more credible market projections is considerably enhanced.

Further detailed analyses of the market potential will provide a firm foundation upon which to construct more detailed program plans and a low risk basis for proceeding with conceptual phase funding.

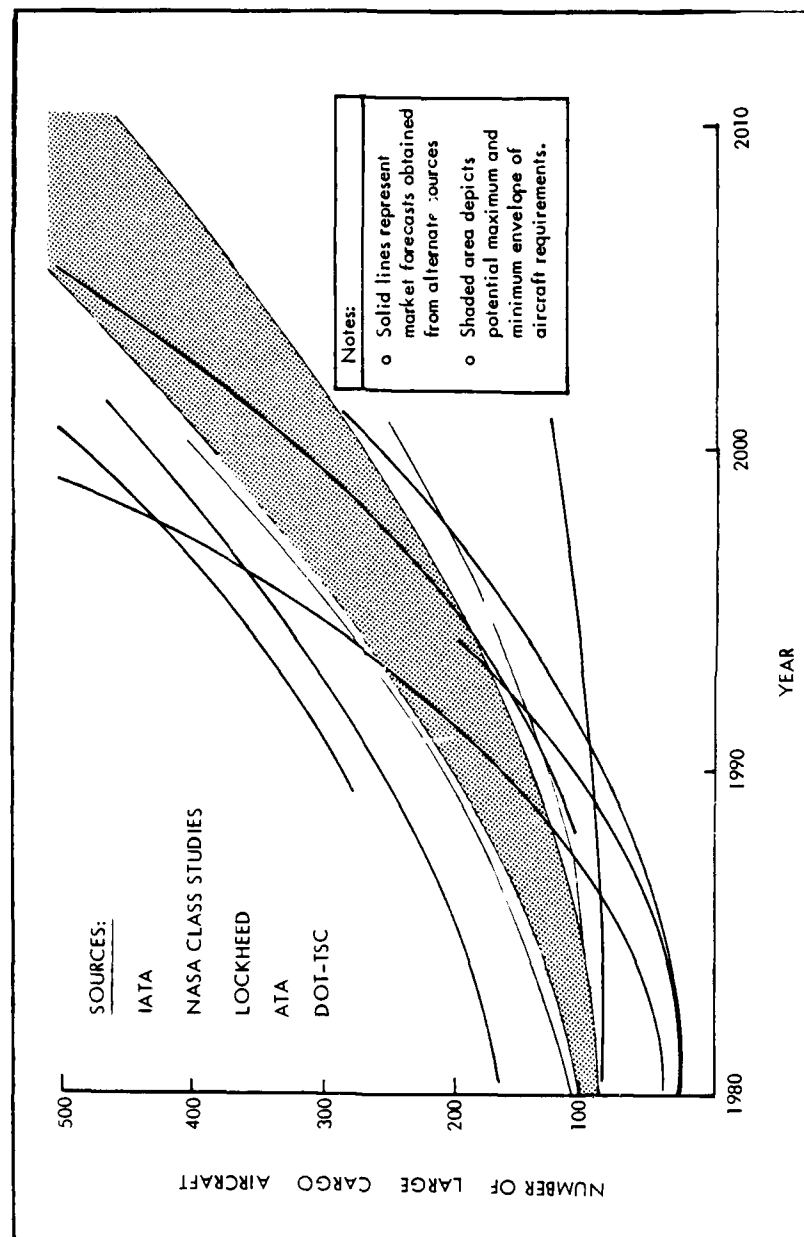


Figure 3. Free World Market Forecasts

INTEGRATING THE COMMERCIAL AND MILITARY NEED

As noted, the ACMA concept has evolved primarily in response to national defense needs for increased airlift capabilities to meet potential contingencies.

Initially, in 1974, the ACMA was envisioned as a large cargo aircraft that would incorporate certain design features to enhance its military utility. Continuing uncertainties of the future air cargo market, coupled with the prohibitively high aircraft unit cost and the growing military requirement for airlift, resulted in a modification to the concept.

Thus, the ACMA is now conceived as a large-cargo capable transport designed to serve both as an organic military aircraft and as a CRAF resource during periods of national crises. Incorporating the latest technology, the ACMA would offer significant improvements in economics and will prove highly attractive as a commercial air freighter to U.S. and international operators/investors as well. (See, for example, References 10 and 11.) To this end, MAC has evidenced a willingness to compromise on those design features that might degrade the commercial profitability of the ACMA.

Direct participation by commercial carriers is anticipated throughout the joint development program, producing such mutual benefits as:

- o Lower average unit flyaway costs for both civil and military users resulting from larger production quantities.
- o Amortization of development costs over a greater number of units.
- o Cost savings made possible by the commercial maintenance of organic military aircraft.

To help confirm that an ACMA can be designed to be commercially and militarily superior in terms of utility, cost-effectiveness, and profitability, Lockheed conducted a parallel study for ASD, known as the Design Options Study. After examining the design aspects of a joint civil/military transport aircraft, this study concludes that commonality can be achieved without unacceptable penalties accruing to either sector (Reference 12).

In addition, because of the magnitude of the funds required, and because the primary motivating factor behind the development concept is the national defense need, it is generally accepted that the government would provide all front-end financing.

SUMMARY OF FINDINGS

There is a considerable base of support within the airline industry for the concept of a joint civil-military airlift development program. There are however, differing views on specific air carrier requirements.

There is a strong consensus that the success of such a cooperative venture will be heavily dependent upon the degree to which the civil sector will be allowed to participate from the outset as an equal partner. Since the driving force for the initiation of such a program is the national defense airlift requirements, it is generally concluded that the government would provide all front-end financing.

And, although the developing civil need for a new large transport aircraft is not dependent upon government compensation, the incorporation of military features which may degrade the commercial profit potential of such a system may require compensation.

The operation of a world-wide fleet of commercial cargo aircraft must be supported by a sufficiently large cargo market to justify a reasonably large number of the aircraft. Although none of the present cargo market forecasts provide the necessary basis for establishing the potential civil market for a new advanced technology cargo aircraft, there is little disagreement among those consulted that a commercial need for a new cargo aircraft to satisfy the projected growth in the air cargo market in the late 1980-1990 time period does exist. The big question seems to be the size of the U.S. and international markets.

We recommend therefore, that early consideration be given to developing a specific initiative under the sponsorship of an appropriate government agency for the purpose of conducting a comprehensive, in-depth market analysis as a basis for validating both the size and timing of the world-wide market requirements for a new large advanced technology cargo-capable transport aircraft for use in the 1990 time period.

III. THE DEVELOPMENT OF A FINANCIAL PLANNING CONCEPT

The investment of federal funds to support large scale, high-cost, technology developments beneficial to private enterprise is an activity with many precedents—atomic energy, synthetic rubber, hydro-electric projects, research in coal utilization, solar energy, and synthetic fuels all come under this category. Government support to transportation has included commercial-type developments such as: steamships, the nuclear ship, the hydrofoil ship, the St. Lawrence Seaway, inland waterways, the high-speed train, the Alaskan and Panama Railroads, and more recently, rapid transit systems.

Thus, the concept of a joint government/industry partnership is not new. What is new is the official recognition at the national level that during this time of increasing costs and diminishing resources, significant improvements in air cargo transportation efficiency and economics is a need that must be explored cooperatively.

The financial planning issue is perhaps one of the most subjective of the many complex problems inherent in a civil-military aircraft development program because of the multiplicity of interdependent influences which either directly or indirectly affect the successful initiation of such a program. The concept of a cooperative program of this type is without precedence. In comparison, the Supersonic Transport program was relatively straightforward, since it was designed to satisfy the commercial passenger market and actively involved only one agency of the Federal Government — The FAA — along with aircraft and engine manufacturers and the airlines. The present concept has the added complexity of satisfying both civil and military needs. If pursued, it will involve several federal agencies in various active roles as well as potentially involving, in a major influential sense, a significant number of foreign aviation interests.

The successful accomplishment of such a joint venture will, however, require a comprehensive financial planning concept such as the one detailed here.

APPROACH

The approach used to analyze this particular issue is described below; Figure 4 shows the relationships of the various tasks.

We reviewed various government-industry joint ventures to examine the financial policies and principles employed. From these, detailed examples which we considered representative of the various options being pursued in proposed or current major programs were selected as a basis of precedence for potential application to a civil/military cooperative airlift development program. Four of these programs are discussed.

Next, the commercial and military acquisition practices and policies were examined in detail. Since early contacts with Federal Procurement Policy officials revealed the fact that the procedures and principles outlined in OMB Circular A-109 must be followed in gaining governmental approvals and funding of a joint program, we developed a representative program planning schedule using A-109 as a basis. This schedule provides a framework for postulating the relative time-phasing of key program events.

A review of the MAC Statement of Operational Need (SON) (Reference 4) was also made to establish a minimum quantitative basis for sizing the potential military organic strategic intertheater fleet requirements. In addition, the various source documents reflecting the free-world commercial market forecasts for cargo aircraft were examined. Since projections contained in these documents generally do not address the perceived needs beyond the year 2000, and our representative program planning schedule studies indicate that initial production deliveries of a new large cargo aircraft could be as late as 1994, the Lockheed Commercial Market Research Staff developed an extended commercial market projection through the year 2010. These projections also provided the basis for estimating the market share.

A quantitative assessment of the consolidated capability needs of both the military and civil sectors was made to provide a basis for postulating the characteristics of the potential market. Advanced design studies (such as the Air Force Design Options studies which pertain to the preliminary design

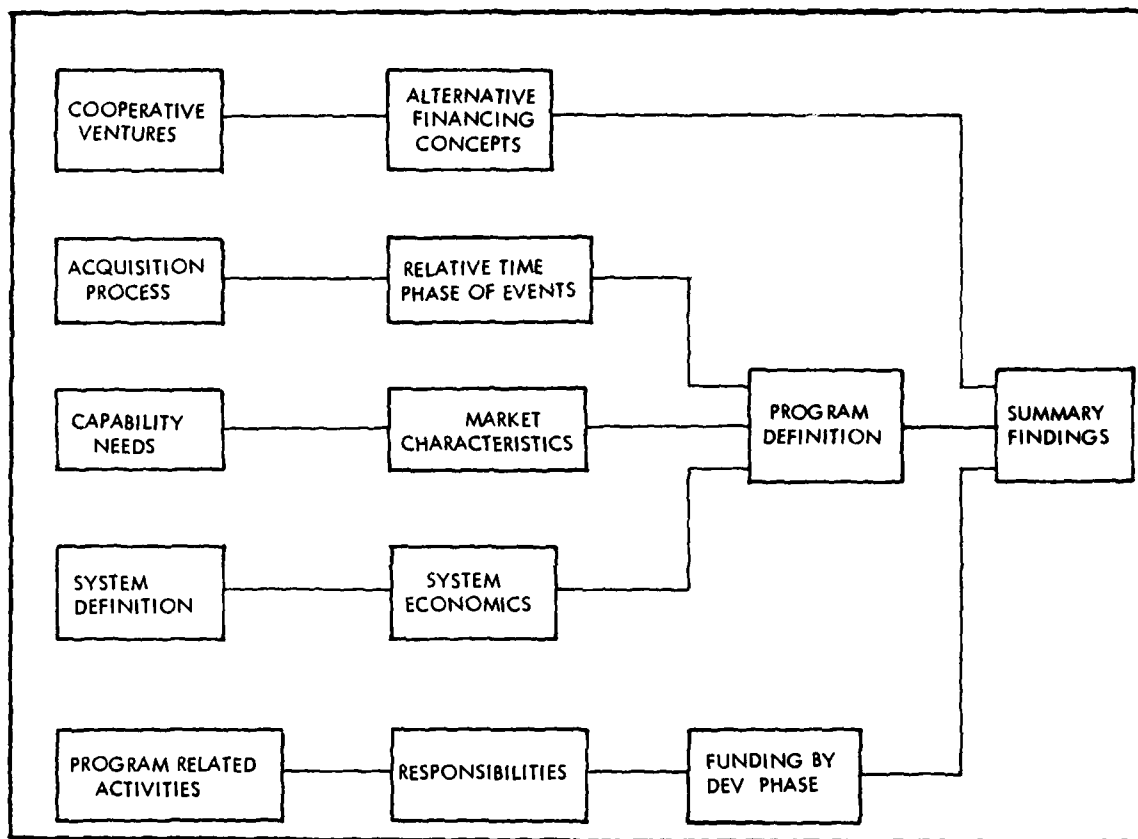


Figure 4. Financial Planning Approach

feasibility of an ACMA) were examined. The influence of improved system economics and the various program interrelationships were also considered.

Next, time phasing of system development and acquisition were integrated with projected civil and military operational needs to provide a basis for the development of a representative operational program. This was followed by a brief analysis of the potential implications of the fleet mix between the size of military organic fleet requirements and those civil aircraft resources committed under the Civil Reserve Air Fleet. Financial planning concepts were then developed which cover the conceptual, validation, and development phases of a cooperative civil/military program.

COOPERATIVE VENTURES

In pursuit of conceptual approaches to financing, four government-industry cooperative ventures were selected for detailed examination. These four are of particular interest because of the different financing concepts and principles employed. These represent four distinct approaches to financing; yet, all either directly or indirectly depend upon federal funding for research and development efforts.

A brief review of some of the more important features of these government-industry cooperative ventures, along with a summary assessment of each are presented here.

The Proposed National Air Cargo Fleet

In the first example, Figure 5, "en route" financing was to be provided by the carriers with government assistance in the form of private loan guarantees. Certain constraints were imposed, however. For example, a \$75 million limit was stipulated for an individual airline; but an addition of up to \$10 million was allowed for the purchase of specialized components of a cargo airlift system. Although supported by a small number of operators and all-cargo carriers, almost all major trunk carriers failed to support the proposed financial plan. Their views ranged from no interest to direct opposition, primarily because the government guarantee might be construed as a form of subsidy—and they wanted no part of such an arrangement.

- Proposed March 1959 - FAA Administrator Quesada
- "Uncompromised" Cargo Aircraft Adaptable to Common Military and Civil Needs
- Operating Costs Competitive with Surface Transport
- Government Guaranteed Loans to be Available to Carriers
- 3/4 of Fleet Would be in Commercial Service Until Needed in Emergency
- Legislation Sponsored by Chairman, Senate Commerce Aviation Subcommittee
- Lack of Support from Trunk Lines of Guaranteed Loans Effectively Killed Program

Figure 5. Proposed National Air Cargo Fleet Act

The Merchant Marine Act

In the second example, Figure 6, the financing concept was, and still is, based on government subsidies. The act, as amended, provides for both construction and operating differential subsidies. Construction differential subsidies provide funds directly to shipyards to compensate for the difference in construction costs between U.S. and foreign yards. Payments of up to 45 percent of overall ship construction costs are provided. There are a number of specific regulations and controls imposed on operating differential subsidized companies. Because of the many restrictions contained in the law, the operators, to a considerable degree, become instruments of governmental policy when they enter into contracts with the Maritime Administration.

The Supersonic Transport Program

The third example, Figure 7, was based on yet another financing concept. A cost-shared development formula was established in which the government would provide the majority of funding to meet the high development costs. Aircraft and engine manufacturers provided the balance of these "front-end" costs. This ratio was initially established as 75/25 and was later changed to 90/10. Initially, a \$200,000 deposit for each delivery position was assessed against the airlines. This was later increased to \$500,000. Monies were collected from both U.S. and foreign carriers for some 90 delivery positions. Airline participation was based on a system of royalties. Federal R&D funds were to be recouped over a period of 12 years at a rate of 1-1/2 percent of gross revenues per year.

The Communications Satellite Act

The last example, Figure 8, reflects a fourth approach to financing a joint government-industry venture. This act basically provided the authority for the creation of a private corporation whose prime objective was to provide a service for profit. Its purpose was to develop and operate communications services through a system of satellites on a world-wide basis. To provide the necessary financing, the act authorized the issuance of capital stock at a

- Originally Passed in 1936 and Amended in 1970
- Provides Construction Differential Subsidy
 - Construction of 300 New Ships - 10-Year Period
 - 35% to 45% of Construction Cost
- Operating Differential Subsidy
 - Wage Differentials and Vessel Insurance
- Cost of National Defense Features Reimbursed by Government
- Indirect Subsidies Include Tax Incentives and War Risk Insurance
- Changes in World Ship Building Market and Continued Foreign Competition in Both Ship Building and Ocean Borne Commerce Severely Impacted Attainment of Objectives

Figure 6. Merchant Marine Act

- National Supersonic Transport Program - January 1961
- Government-Industry Program
 - Government assistance to meet high development costs
 - Airline repayment of public funds through system of royalties
- Cost-Shared Development Cost
 - 75/25 later 90/10
- Airline Royalty Payments for Delivery Positions
 - Initial \$200,000 later \$500,000
- Reimburse Government Development Costs
 - 1-1/2 percent of gross for 12 years
- U.S. and Foreign Airline Participation from Beginning

Figure 7. Supersonic Transport Program

- Act Authorized Creation of Comsat Corporation
 - Private corporation for profit, not agency or establishment of U.S. Government
- Corporation Purpose
 - To plan, initiate, construct, own, manage and operate, in conjunction with foreign governments and business entities, a commercial satellite system
- Key Provisions Included
 - Corporation authorized to issue capital stock
 - Price per share not to exceed \$100 to encourage widest possible distribution to American public
 - 50 percent of shares of voting stock reserved for purchase by communications common carriers authorized by FCC
 - Carriers in aggregate entitled to make purchase of those reserved shares in total number not exceeding total number of non-reserved shares
 - Corporation will observe policies and practices as will preserve competition
 - All communications common carriers shall have non-discriminatory use of, and equitable access to, system
 - Service to foreign points will be established whenever National Policy requires
 - Activities will be consistent with relevant U.S. foreign policies

Figure 8. Communication Satellite Act of 1962

price not to exceed \$100 per share to encourage the widest possible participation by the general public. Fifty percent of the voting stock was reserved for purchase by FCC-authorized communications common carriers. This ratio was to be maintained in all subsequent stock offerings. Additionally, other non-voting securities, bonds, debentures, and other certificates of indebtedness were authorized, subject to the approval of the FCC. The law further provided for the establishment of a 15-man Board of Directors to manage the corporation: six elected by the communication common carriers, six elected by the other public stockholders, and three appointed by the President with the advice and consent of the Senate.

SYSTEM DEVELOPMENT AND ACQUISITION

To provide an initial base of reference for the exploration of financial concepts for the development, acquisition, and operation of an advanced civil/military air cargo system, it was first necessary to examine both the commercial acquisition process and the military system acquisition process and procedures. These are briefly described below.

Commercial Acquisition Process

The normal acquisition process for commercial aircraft differs markedly from the process for military aircraft. The needs of the market place are continually researched by the airlines and aircraft manufacturers. The manufacturer develops the aircraft configuration and program plan at risk; firm commitments are not established until sales agreements are completed. Major pre-go-ahead activities are dependent upon the establishment of a favorable market forecast. When conditions indicate a need for new equipment, the competitive forces interact until a viable program evolves. This process involves securing orders for a sufficient number of aircraft so that the overall risk is low enough to warrant go-ahead along with the necessary financial commitments. After go-ahead, the design and manufacturing process is closely monitored by the aircraft customer and the FAA.

Military System Acquisition Process

The acquisition process for military aircraft is far more complex and formal than the commercial process. The process is initiated with a precise description of the military operational deficiency. This is reduced by an analysis process to a definition of functional requirements for the system needed, and finally to the establishment of the system design specifications. The design/development process is closely monitored, and tests are required to reduce the risk of performance and operational failures.

OMB Circular A-109 - This circular establishes policies to be followed by all executive branch agencies of the Federal government in the acquisition of major systems. Among other things, A-109 covers and applies to the determination of mission needs, setting of program objectives, system program planning, budgeting, funding, research, engineering development, testing and evaluation, contracting, production, and program and management control, and its introduction into use. It also applies to all programs for the acquisition of major systems, even though the system is one-of-a-kind and/or the agency's involvement in the system is limited to the development of demonstration hardware for optional use by the private sector rather than for the agency's own use (Reference 13).

There is no specific policy guidance outlined on OMB A-109 that is directly applicable to the documentation and processing of a civil need under a joint government-industry major system acquisition program. However, representatives from the Office of Federal Procurement Policy have informally advised that the policies outlined in A-109 are sufficiently flexible to accommodate a joint government-industry program.

Other Directives - Although any major program initiative in which the Federal Government is expected to play a primary role will be governed by the policies outlined in A-109, the procedures for documenting and processing a projected need are further defined in implementing directives published as DoD Directive 5000.1/5000.2 and Air Force Regulation 57-1 (revised) (Reference 14).

PROGRAM INITIATION CONCEPT

Based on the government acquisition policies and procedures just discussed, we devised a Program Initiation concept which we suggest could meet the needs and requirements of both government and industry. The plan, described below, begins with the establishment of the government need for additional airlift. Then, the major actions that would be initiated by the principal government-industry agencies are presented.

Statement of Operational Need (SON)

A Statement of Operational Need (SON) (Reference 4) was prepared and published on 10 August 1979 by the Military Airlift Command (MAC) in accordance with current directives. It was subsequently reviewed and the concept was validated in January 1980 by Headquarters, USAF. The SON is unique in that it addresses both the projected needs for organic military intertheater airlift capabilities and the need for airlift augmentation capabilities to be provided by the private sector under the Civil Reserve Air Fleet (CRAF) program. This document identifies operational deficiencies and states the need for new or improved airlift capabilities to satisfy the increasingly more critical demands for timely response to national defense commitments on a world-wide basis.

MISSION ELEMENT NEED STATEMENT (MENS)

Following validation of the SON, procedures provide for the the preparation and processing of a draft Mission Element Need Statement (MENS) by the Air Staff following the outline shown in Figure 9. In accordance with existing directives, the draft MENS is then reviewed by the Air Staff Requirement Review Group prior to its validation by the Secretary of the Air Force. The validated MENS is then forwarded to the Secretary of Defense with a recommendation for approval. Approval of the MENS by the Secretary of Defense constitutes the go-ahead for the program to enter the conceptual phase.

- I. MISSION
 - A. Mission Area
 - B. Mission Element
 - (Stated in terms of functional capabilities required--not hardware)
- II. THREAT
 - (Projected threat over period of time for which capability is required--quantification of threat in numbers and capability.)
- III. EXISTING AND PLANNED CAPABILITIES TO ACCOMPLISH THIS "MEN" TASKS
 - A. Briefly summarizes the existing and planned DoD and allied capability to accomplish this mission. (This section references existing documentation such as DCPs or Force Structure Documents.)
 - B. Agency/Component(s) Involved
- IV. ASSESSMENT
 - The need is assessed on one or more of the following terms:
 - A. Deficiency in Existing Capability, e.g., Excessive Manpower, Performance, etc.
 - B. Technological Opportunity
 - C. Force Size or Physical Obsolescence of Equipment
 - C. Cost of Savings Opportunity, Life Cycle Cost Potential for Savings
 - E. Vulnerability of Existing Systems
- V. CONSTRAINTS, SUCH AS:
 - A. Affordability in Relationship to the Overall Service Budget
 - B. Relative Priority Within Mission Area
 - C. Logistics and Manpower Considerations
 - D. Timing of Need
- VI. IMPACT OF STAYING WITH THE PRESENT CAPABILITY, SUCH AS:
 - A. Ability to Meet Projected Threat, Impact on Combat Effectiveness
 - B. Cost of Increasing Quantity of Existing Equipment to Meet Level Threat

Figure 9. Mission Element Need Statement

The military MENS is a very structured document, as shown in Figure 9, and at first reading may not appear to lend itself readily to commercial documentation. However, we formulated a commercial version of the MENS as shown in Figure 10 by substituting the commercial equivalents "Business Sector" and "Opportunity" for the military "Mission" and "Threat." Review of this "Commercial MENS" by the various consultants resulted in general agreement that it is a format that can be adopted by the civil sector. Since the MENS is an existing part of the documentation process required by the government, utilizing an already acceptable (and familiar) format would help to expedite the decision-making process to initiate program funding.

Representatives of the principal agencies which would be involved in reviewing and processing a joint civil/military need further suggested that a draft joint civilian-military MENS be prepared to incorporate inputs from, and be coordinated with, major potential commercial operators prior to submission to the Secretary of Defense. It is suggested that review by, and support from, the Joint Chiefs of Staff (JCS) would provide additional influence in obtaining support from other Executive agencies and the Legislative branch of the government.

Thus, before the draft joint MENS is submitted to the Secretary of Defense, it would be forwarded through the JCS for review and support. We then envision that action by the JCS to obtain formal coordination on the conceptual requirements outlined therein, including signatures of senior operating executives from appropriate major carriers, would provide the necessary documentary confirmation of serious interest by the commercial sector. The Joint MENS would then provide a valid basis for a Milestone "O" decision by the Secretary of Defense for the initiation of the conceptual phase of the program, as indicated in Figure 11.

In addition, coordination and support would be obtained from NASA, the Department of Transportation, the Department of Commerce, regulatory agencies, and others as appropriate. This action would provide a formal basis for action by the Secretary of Transportation to fulfill those responsibilities outlined in the Statement of National Transportation Policy, dated September 17, 1975, to exercise:

- I. BUSINESS SECTOR (PRODUCT AND/OR SERVICE TO BE OFFERED)
 - A. Market--Introduction, Commerce, Transportation, Economic Growth, Technological Change
 - B. Market Sector--Partition the Market into Sectors, Identify the Functional Characteristics of the Sector to be Served
- II. OPPORTUNITY

(Quantify the Market Over the Period of Time Involved. Discuss Market Enhancement Resulting from Functional Capability to be Offered.)
- III. EXISTING AND PLANNED CAPABILITIES

(To Meet the Need Expressed for the Market Sector and the Opportunity)

 - A. Summarize Existing and Planned Capabilities
 - B. Participants/Competitors
- IV. ASSESSMENT
 - A. Forecast the Competitive Developments in the Market Without Enhancement
 - B. Discuss Impact of Enhancement
 - C. Overall Economic Impact
 - 1. Domestic Economic Aspects
 - 2. International Aspects (Including Balance of Payments)
 - D. Political Considerations
 - E. Technological Aspects
 - F. Energy Balance
 - G. Environmental Impact
- V. CONSTRAINTS AND GUIDELINES
 - A. Free Enterprise Aspects, Overall Competitive Picture
 - B. Anti-Trust, Regulatory
 - C. Public Interest
 - 1. National Defense
 - 2. Economic Payout
 - 3. Quality of Life
 - D. Functional Design Guidelines
- VI. ALTERNATIVE OF STATUS QUO

(Start with IV.A. above and summarize other aspects covered in IV. and V. to include total picture in addition to the market.)

Figure 10. Proposed Commercial Need Statement

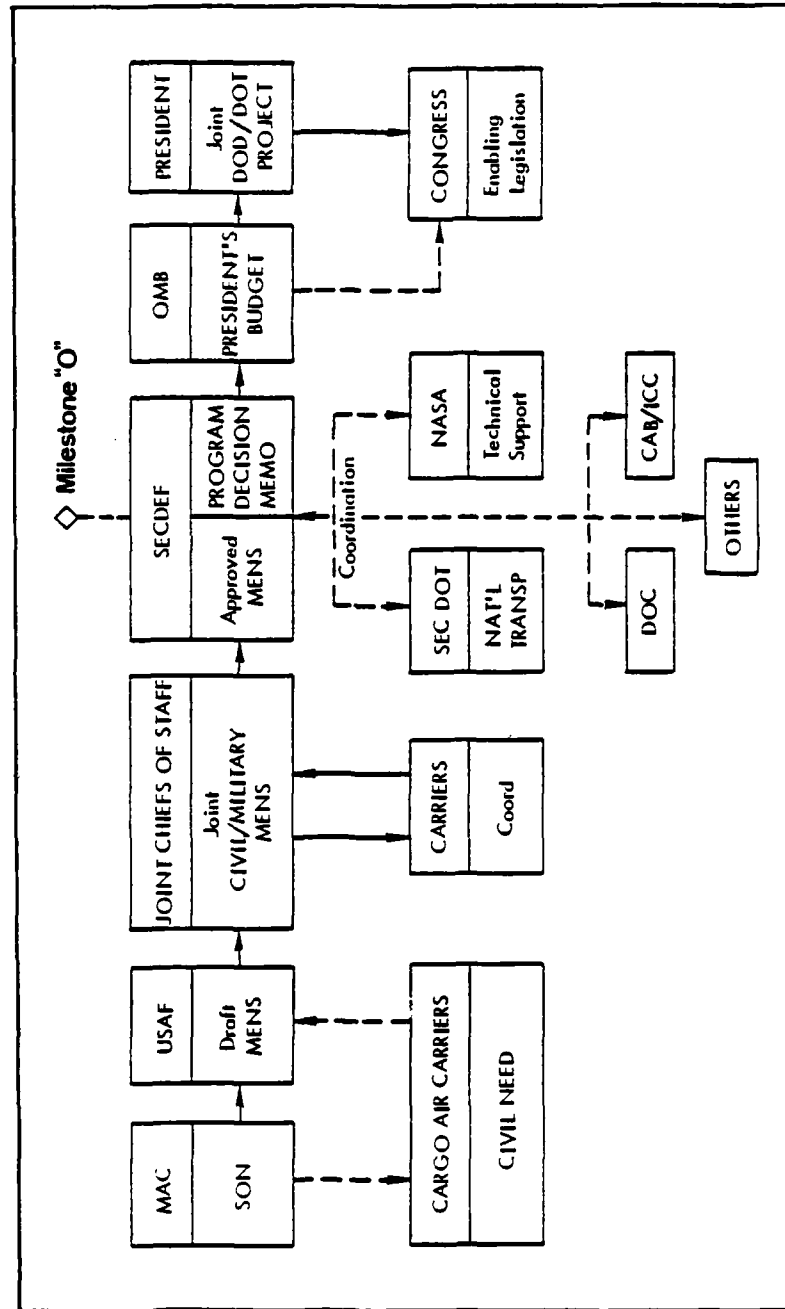


Figure 11. Program Initiation

Federal leadership in stimulating new technology—needed to save substantial costs in future capital investment and operating expenses (and) to anticipate long term transportation needs and to support integrated transportation policy.

Coordination solicited from NASA would include continuing active technology development support, including trade studies, to ensure the technical feasibility of proposed alternative solutions.

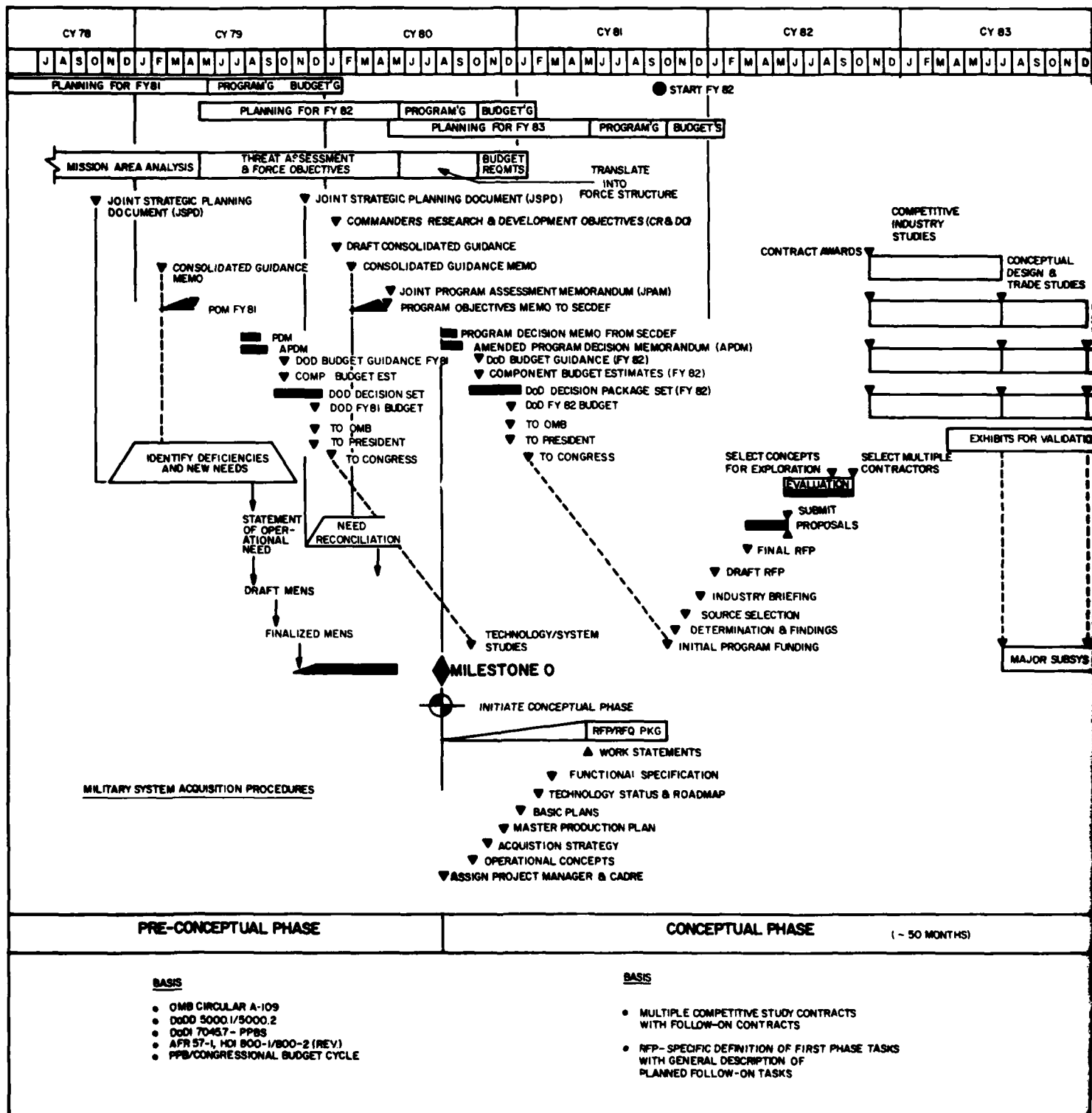
The final program package, forwarded through OMB, would then provide the basis for Executive and Legislative Branch support for a program of urgent national priority.

REPRESENTATIVE PROGRAM PLANNING SCHEDULE

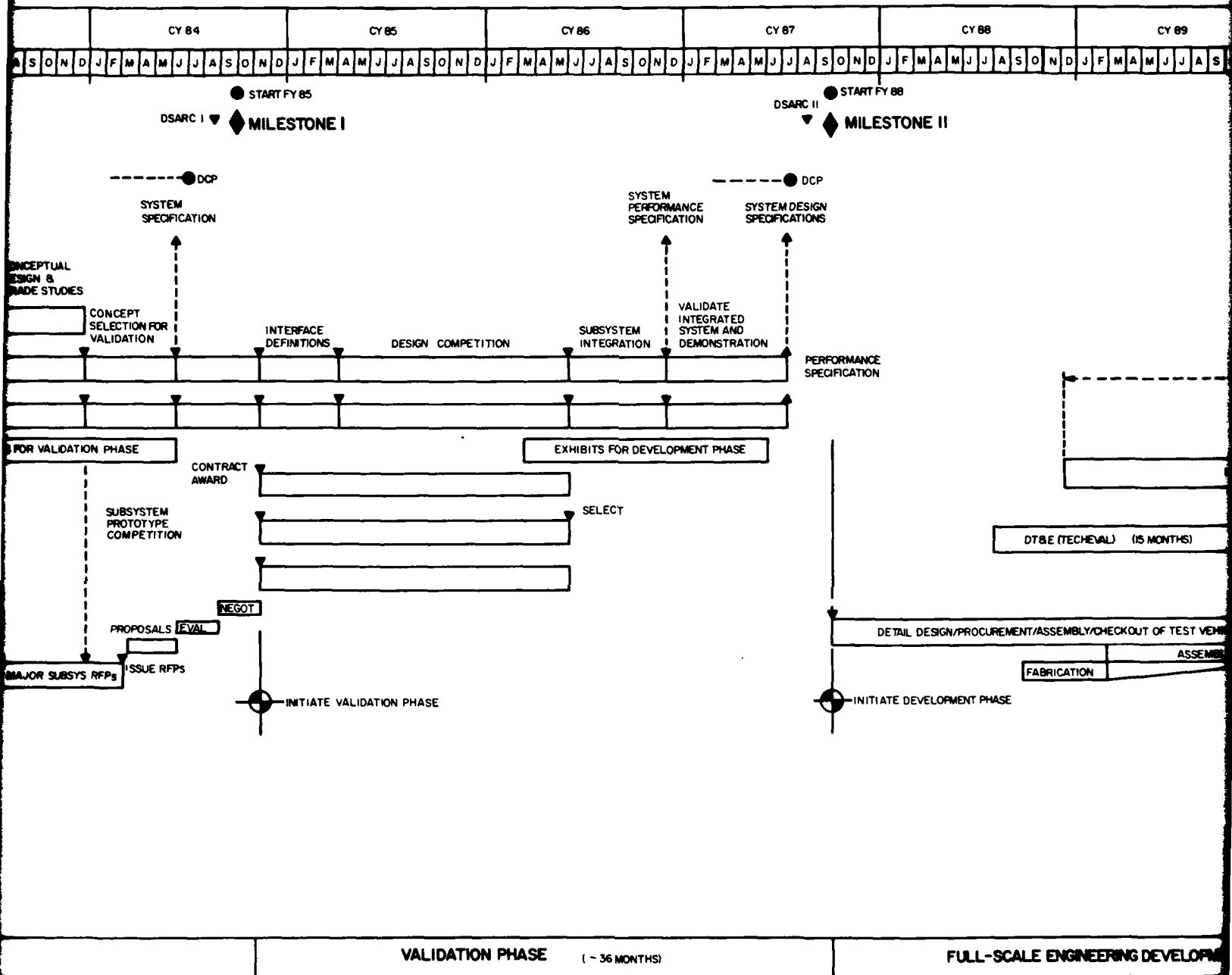
A representative program planning schedule, shown on the foldout as Figure 12, was prepared based on policy guidelines and procedures outlined in appropriate acquisition and budgeting directives. Time spans reflected on the schedule were initially derived from experience gained during several recent major weapon system acquisition programs. Initial drafts of this detailed schedule were reviewed with senior officials within the DoD and OMB. Time phasing of the various detailed program benchmarks generally reflects a consensus of these senior officials. The specific comments and guidance provided by these officials were incorporated into the final representative planning schedule shown here.

It should be noted that, unless priority actions are indicated, more than 14 years could elapse between the time a decision is made to initiate conceptual studies and the anticipated delivery date of the first production article. The representative schedule shown does not take into account the diverse interests and political implications of a joint civil/military cooperative program. An additional time allowance could perhaps be included to accommodate this dimension.

The representative program planning schedule serves to identify the major development activities and their relative timing. Clearly, certain of these activities are the responsibility of the Department of Defense. For instance, pre-conceptual actions in support of the structured planning, programming, and budgeting process for such a program must be initiated by appropriate agencies within the DoD in accordance with current practices.



REPRESENTATIVE PROGRAM PLANNING SCHEDULE



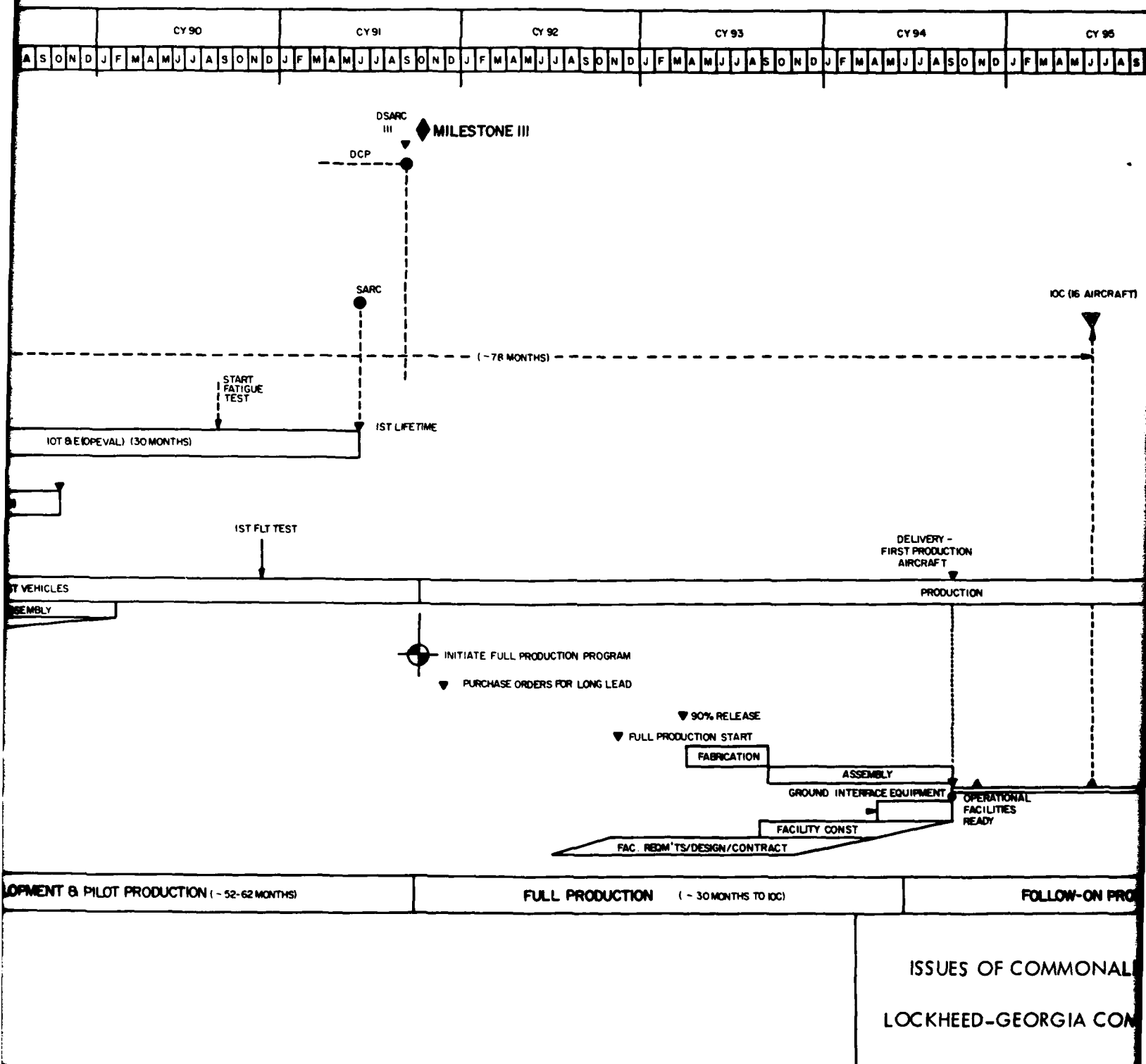
VALIDATION PHASE (~ 36 MONTHS)

FULL-SCALE ENGINEERING DEVELOPMENT

BASIS

- COMPETITIVE PROTOTYPING SIMILAR TO SLCM PROGRAM

2



PROGRAM DEFINITION

While the representative program planning schedule provides a reference for the identification of key events and their relative time phasing, any meaningful exploration of financial planning concepts must be based on a more complete definition of a proposed program. In developing such a basis for postulating the various aspects of a joint civil-military program, the military need analysis supporting the Military Airlift Commands' SON, and the various commercial market projection documents were reviewed. Certain premises related to each have been developed and include: potential growth in the air cargo market through the year 2010; market sharing; the development of derivatives of contemporary air freighters; and the potential payload size and associated economics of a new advanced technology, all-cargo system to be operational in the 1990. The various elements related to the conceptual formulation of a representative operational program are identified and discussed below.

Military Need

The Military Airlift Command's recent SON (Reference 4) for an intertheater airlift vehicle outlines the mission of intertheater airlift and the basic rationale for the requirement for improved capabilities. This unclassified document strongly emphasizes the increasing importance of highly responsive intertheater airlift in support of the rapid deployment of U.S. combat forces to meet national defense commitments world-wide through the 1990s. The SON also cites the requirement to provide replacements for the C-141 and the C-5 airlift fleets as a further justification. Acknowledgement is also made of the potential cost advantages and/or other significant improvements in operational capabilities possible with an advanced technology aircraft, which could result in the earlier replacement of current strategic airlift aircraft.

The critical importance of maintaining a relatively small organic military fleet of aircraft to provide short-notice rapid movement of U.S. and Allied forces provides an essential planning parameter in program definition considerations of a joint development program. A simple block diagram reflecting certain key aspects influencing the relative size of an organic fleet of military ACMAs is shown in Figure 13.

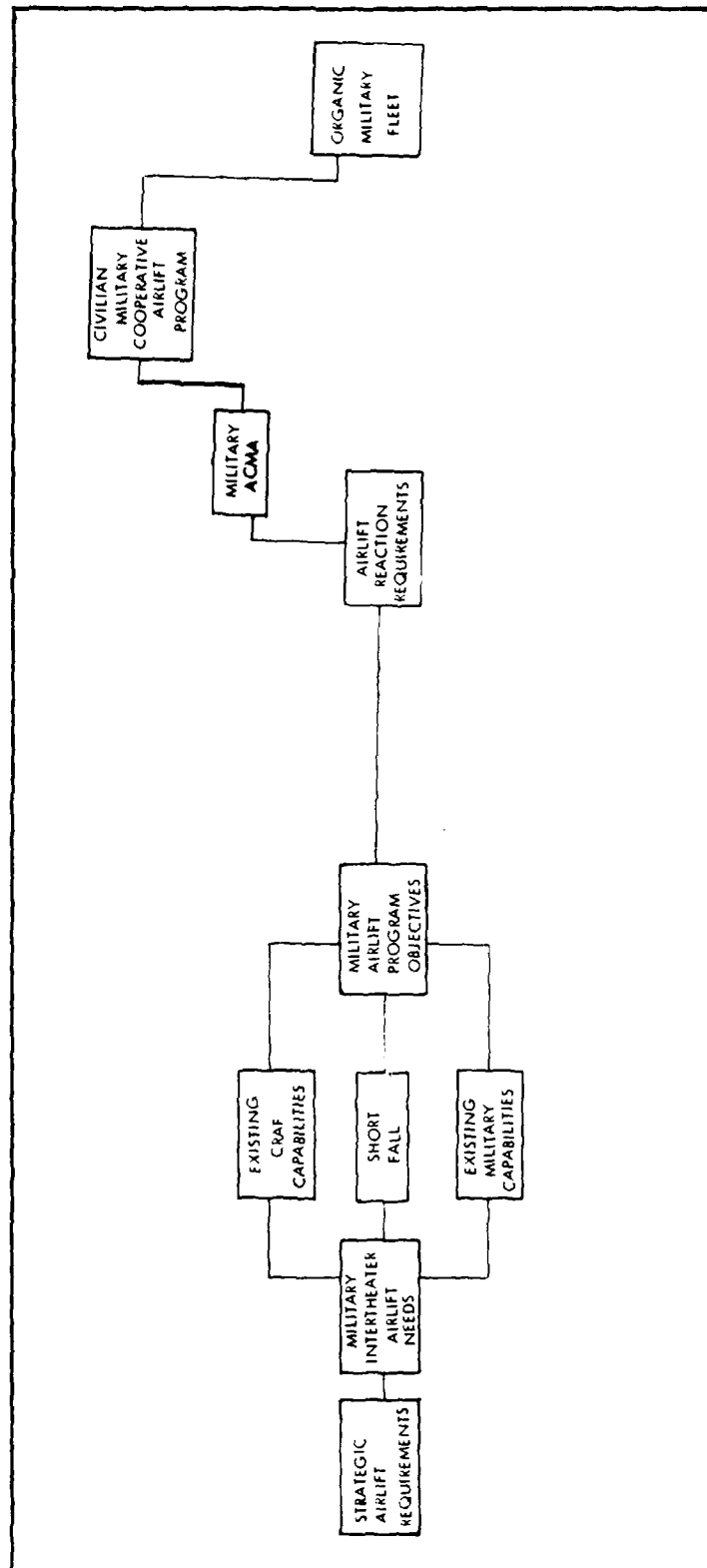


Figure 13. Military Need Derivation

In this study, no attempt has been made to quantify the intertheater airlift resources needed to satisfy the large and increasingly more serious airlift short-fall projected by the JCS. Instead, the need for replacement of the C-141 and the C-5 currently planned to begin in the 1990s is examined. The C-141 was introduced into the MAC operational inventory in the mid-1960s and is presently undergoing "stretch" modification. These aircraft are currently programmed for replacement beginning in 1998. The C-5 fleet, presently programmed for wing modification in order to provide an additional 30,000 hours of service life, is currently projected for replacement starting in 2012. A hypothetical replacement schedule has been developed based on these dates. For the lack of more definitive data, it is assumed that these resources will be replaced at the same rate that they were produced. Figure 14 depicts such a schedule. To provide a comparative basis, the airlift capabilities of these two resources are indicated on a scale in millions of ton-miles-per-day equivalents. Based on this assumed phase-out rate, it should be noted that some eight years may elapse between the completion of the C-141 fleet phase-out and the start of the C-5 programmed replacement.

To establish a minimum quantitative basis for postulating the potential size of large, outsize military aircraft requirements, one design parameter of the new ACMA—a 390,000-pound payload—was assumed. This parameter is based on preliminary results of the on-going Air Force design option studies (Reference 8) as well as discussions with major international all-cargo carriers. Using this payload, the minimum number of ACMA equivalents needed—just to maintain current organic airlift capabilities—is estimated and shown in Figure 15. Note that the number of ACMA equivalents does not reflect those aircraft required to satisfy the growing short-fall projected by the JCS.

Civil Need

As noted in Section II, the projected civil need must be based on more in-depth economic studies of world commerce covering the late 1990s through the turn of the century. The results of these studies will provide an insight into the transportation needs in support of economic growth and changing commodity flows between major centers of world trade. Transportation activity may not reflect the varying short-term growth rates and long-term trend in economic

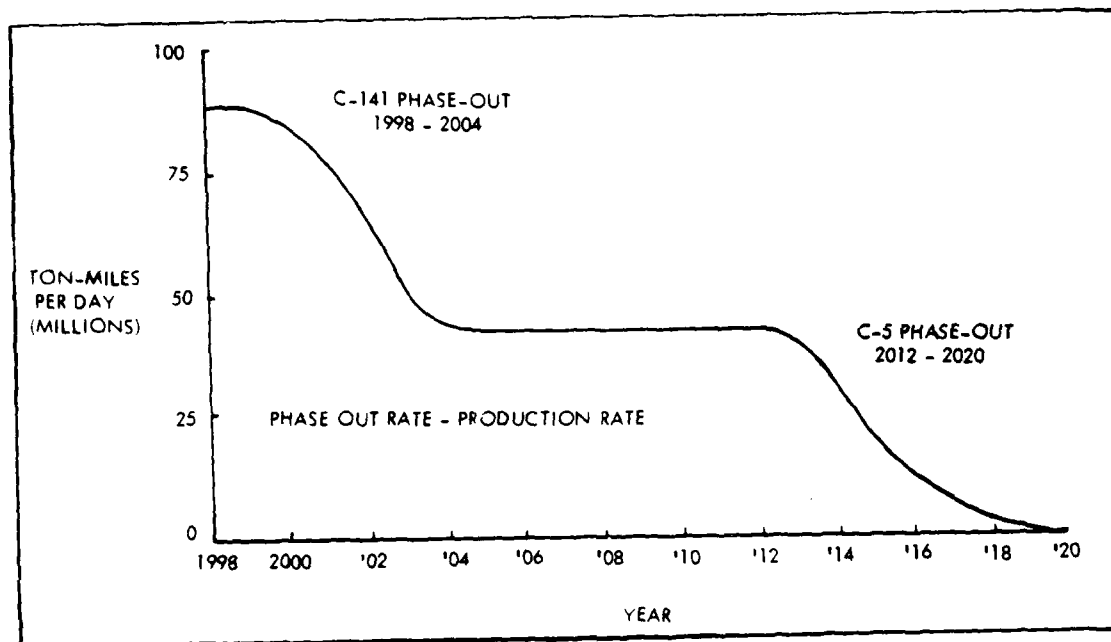


Figure 14. C-141 and C-5 Phase Out

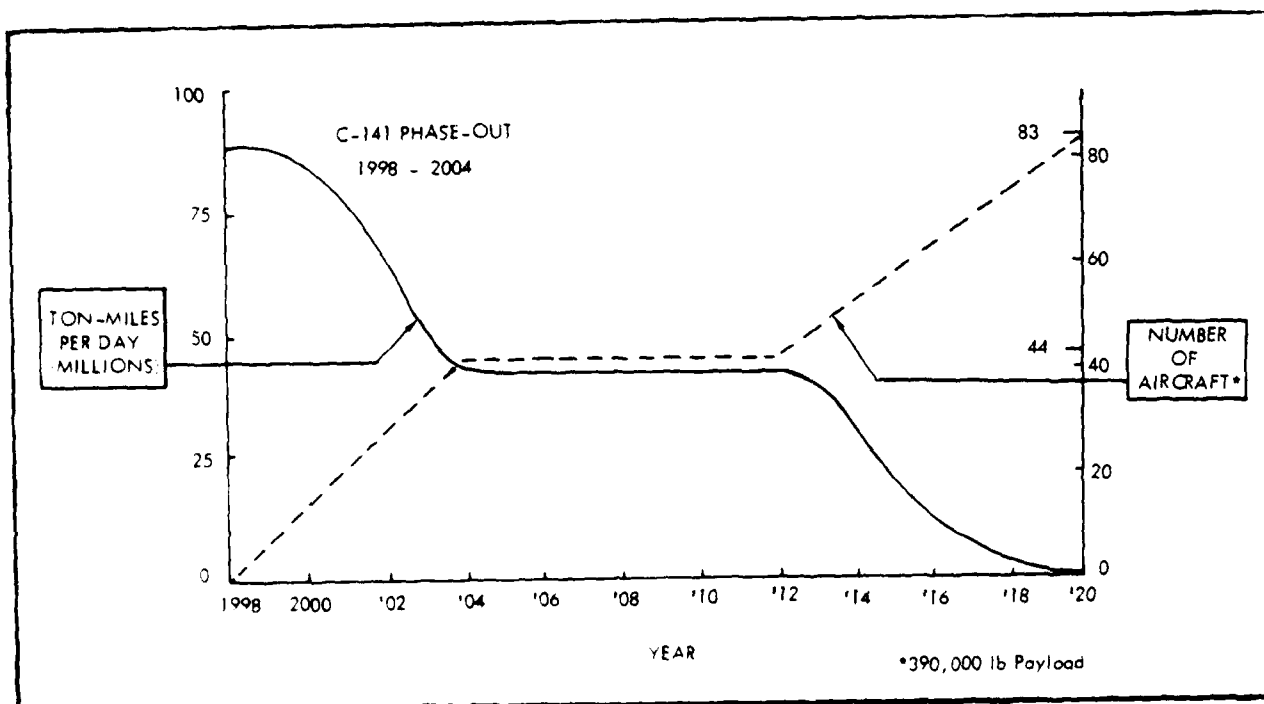


Figure 15. ACMA Equivalents

conditions. Technological change, which is an important determinant of economic growth, is generally the factor that accounts for the high growth rate of some modes of transportation when other economic factors show less growth rate. The importance of these considerations is that the growth rate of innovative, service-oriented transportation is not completely dependent upon the performance of the total economy in the short term. The advent of a new large, advanced-technology cargo aircraft would offer substantial promise for providing improved service to shippers for the routine intermodal shipment of large-volume, oversize loads of general commodities at reduced rates.

The total commercial air cargo needs projected for the future will be satisfied in three ways: existing air cargo capability, domestic new aircraft sales, and foreign sales. Until advanced aircraft are available, the market must be served with existing aircraft. Derivatives of the current wide-body aircraft will be the primary resource available. These aircraft will serve a decreasing share of the market as aircraft with improved economics become available. Satisfaction of the total commercial need for new cargo capabilities must also recognize the significance of the growing belly-hold capacities inherent in the expanding fleet of wide-body passenger aircraft. These capabilities, along with an expanding number of combination-configured contemporary transport aircraft will directly influence the potential market for new all-freighter aircraft in the late 1980s. While a substantial segment of the total market will be represented by small and medium size aircraft, the joint civil/military cooperative development concept addresses the need for large, outsize, long range cargo aircraft.

Potential International Sales

Forecasts of future commercial air-cargo needs for the class of aircraft addressed here indicate that the potential international market is from two to three times as large as the domestic market in 2000. Much of this potential market will be served by international airlines. Thus, the potential for international sales could be substantially larger than the domestic market depending on the development of a competitive aircraft by international manufacturers.

An important consideration in international sales is the necessity for offsets. While offsets can take many forms, the most easily organized is the subcontracting of parts of the development and manufacturing tasks. The basic fact is that international sales may be highly dependent upon provisions for adequate economic offsets in negotiations with the countries involved. The type and value of the offsets will be structured to fill the needs of the specific countries, and they will be determined in a process of negotiation. A simple block-diagram reflecting key aspects and relationships influencing the character and size of the civil need is shown in Figure 16.

MARKET PROJECTION

Although as noted in Section II, various air-cargo growth projections were reviewed to gain an insight into the potential size of the total market for a new improved-capability, large, all-cargo aircraft, only the class studies addressed the potential market beyond the year 2000. Since our representative program planning studies indicate that a new advanced-technology cargo aircraft may not be available for delivery until the mid-1990s, assistance in developing a more extended forecast was solicited from the Lockheed-Georgia Commercial Market Research staff. Figure 17 depicts the overall results of this effort.

As indicated in Figure 17, certain basic premises had to be developed regarding the evolutionary changes in the present all-cargo system. These included a basic assumption that growth demands for large, long-range air freighters through the 1980s will be satisfied primarily by cargo derivatives of the 747 aircraft. We made the assumption that a new growth version of this aircraft with 330,000-pound payload and a gross weight of approximately 1 million pounds with limited improvements in efficiencies could possibly be introduced between 1985 and 1990. This aircraft would be in competition with an advanced-technology ACMA in the mid-1990s. For the sake of making preliminary estimates of the potential market share between these large contemporary derivative aircraft and a civil ACMA, we estimated that the new civil ACMA aircraft would capture 50 percent of the large cargo aircraft market share when deliveries begin. Based on its significant relative advantages in economics and fuel efficiencies, we postulated that the ACMA would satisfy a growing share of the large cargo aircraft market, reaching 100 percent during the 2010 time period.

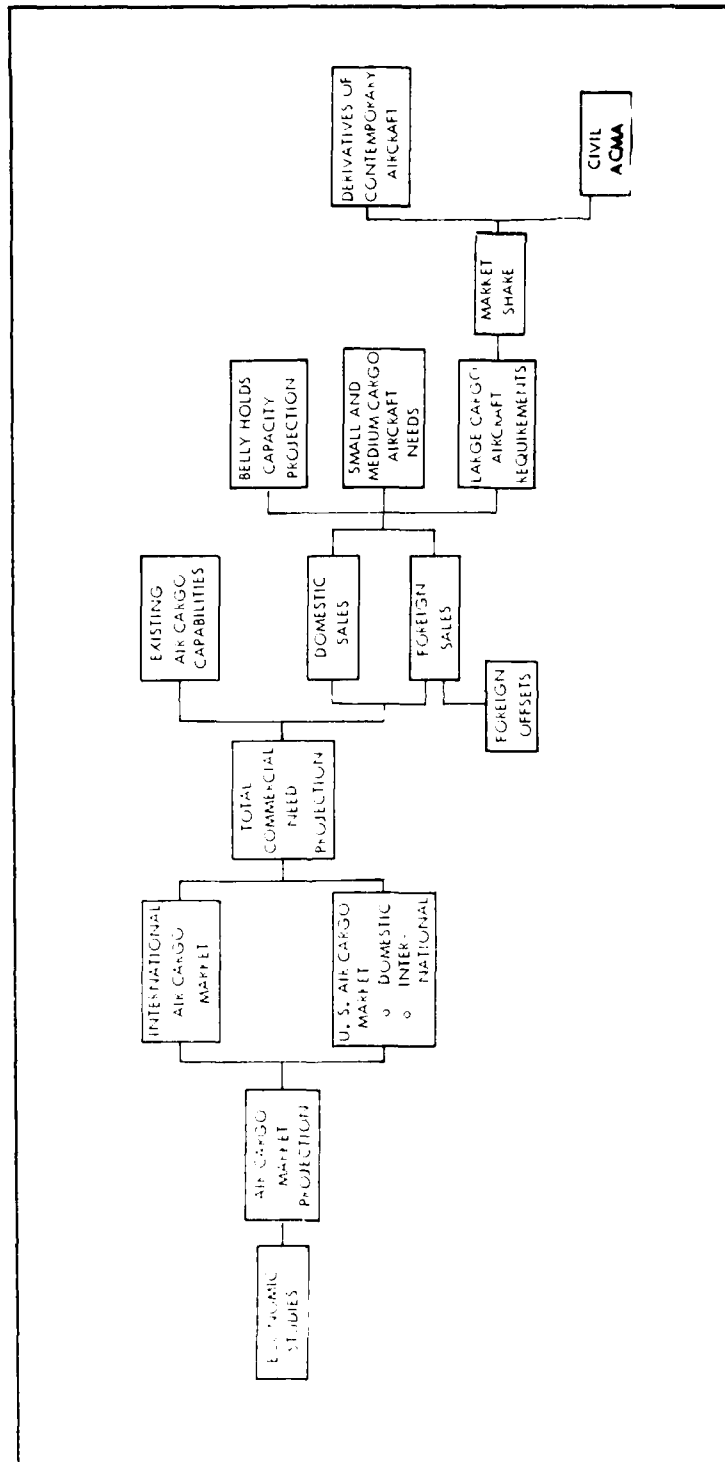


Figure 16. Civil Need Derivation

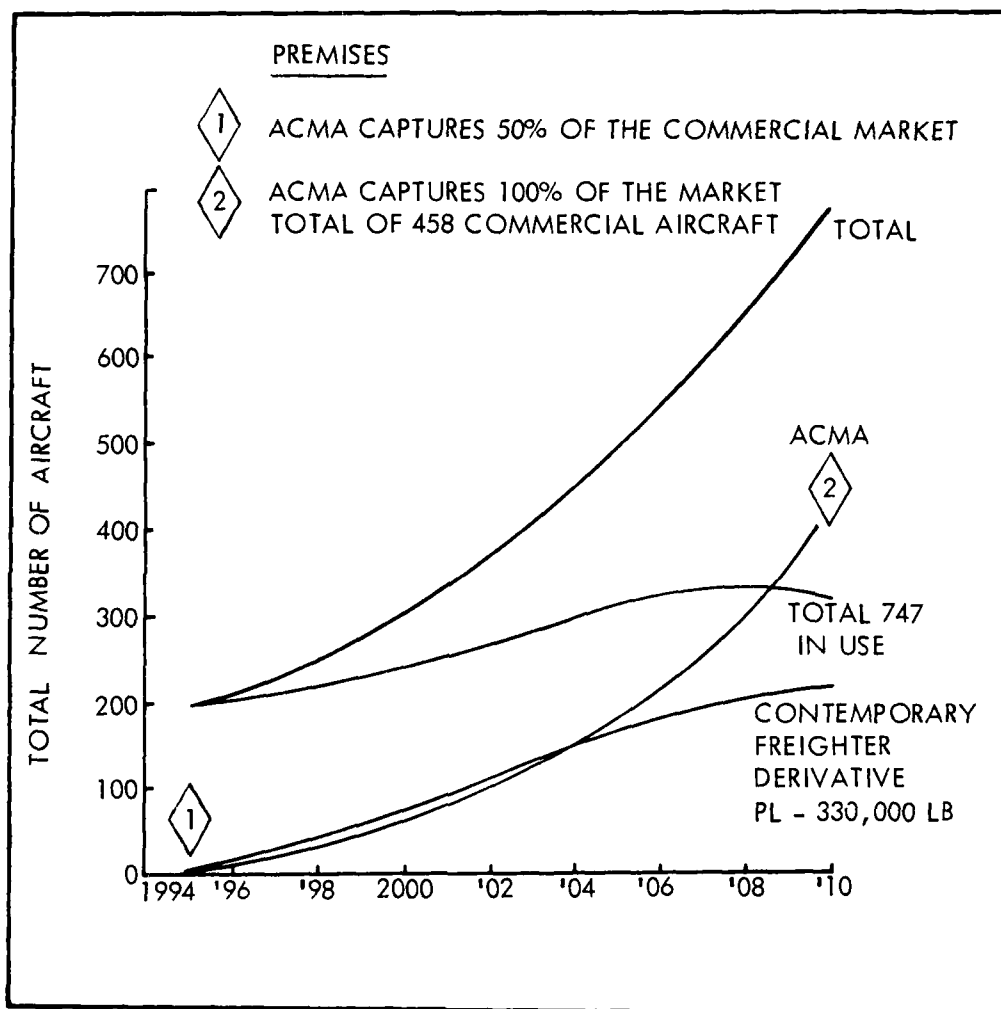


Figure 17. Market Projection and Market Shares

Although this market projection indicates that the projected need for large commercial cargo aircraft could exceed 750, the important point to be established at this early pre-conceptual stage is that it can be reasonably concluded that there is a market for a fairly large number of civil ACMA cargo aircraft. When combined with organic military needs, these civil ACMAs will provide the total quantity of aircraft resources needed to meet national emergency airlift requirements in a timely and effective manner. These combined needs, when fully validated, will provide a realistic basis for soliciting high-level government and industry support for the early initiation of a cooperative development program.

SYSTEM DEFINITION

A dominant influence in determining the ultimate viability of the proposed cooperative development concept is the establishment of design specifications for the system that are mutually acceptable to both the potential civil and military users. The system design activities shown in Figure 18 are integrated activities since they are responsive both to the commercial needs and to the military requirements.

Continuing USAF-sponsored Design Option and NASA-sponsored Very Large Cargo Aircraft studies will provide an essential base of preliminary design data for establishing the technology level to be incorporated into the ACMA. Various potential advanced technological developments will continue to be evaluated and appropriate technology demonstrations will be planned to reduce the risks to acceptable levels. The results of these demonstrations coupled with optimization trade studies will provide the basis for establishing the design features that determine the economic characteristics of the system. These economic characteristics will, to a major degree, determine whether the civil quantitative needs or the military requirements predominate.

SYSTEM ECONOMICS

Whether the ACMA commercial system is accepted by commercial operators will ultimately depend on the economic characteristics of the system in comparison with other competitive systems. If the system has a high profit potential

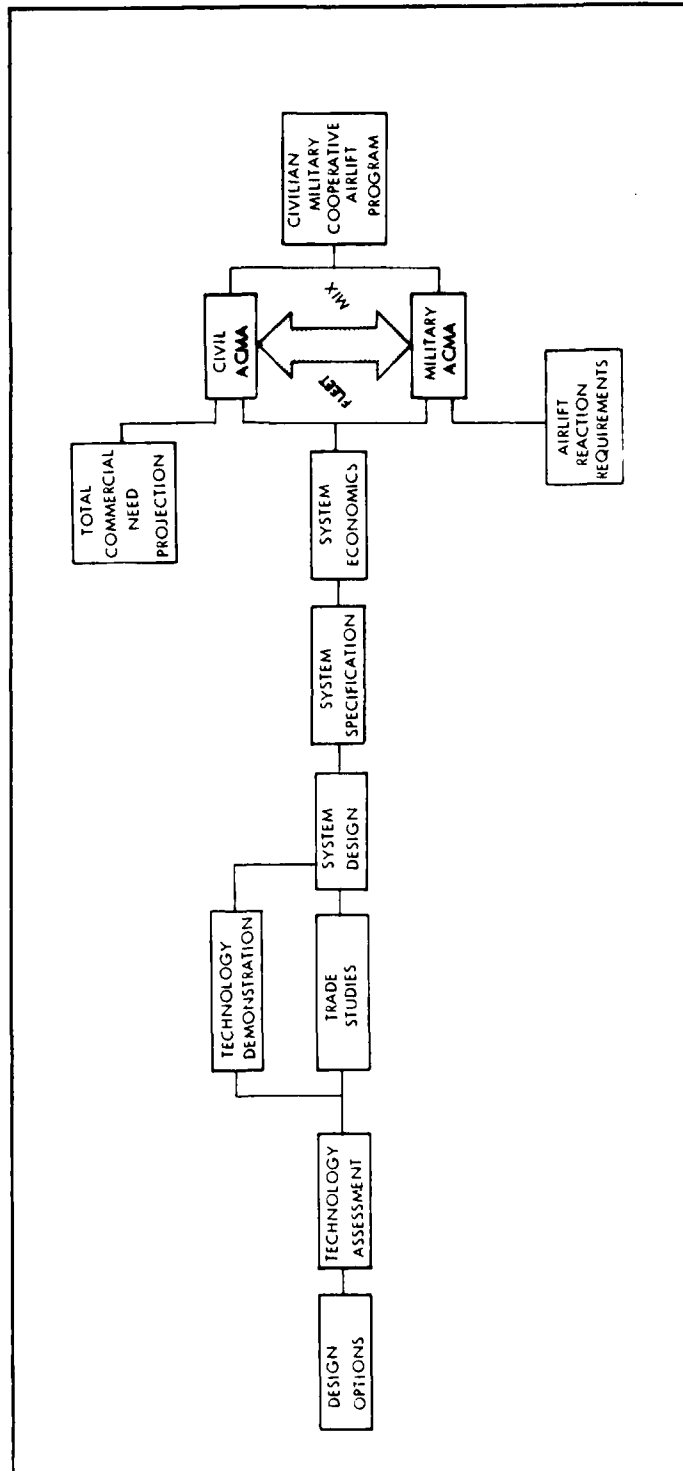


Figure 18. System Definition

compared with existing systems, it will be quickly accepted. Thus, acceptance of the system is design-dependent. Another factor that affects acceptance by commercial operators is how urgently the operators need the aircraft, which relates to the market. There are two characteristics of the market that, among other things, determines how badly the operators will need the aircraft: the size of the market and the timing (Figure 19).

These two factors are interdependent because size of the market is a function of time. Thus, for the civil need to be a driving force for the program, a profit-promising market must exist at the time the full-scale engineering development (FSED) is ready to start.

The critical influence that system economics has on the potential success of the program is further illustrated in Figure 20. Comments by senior representatives of major cargo carriers indicate that, at the very minimum, the economics of any new system must be at least 10 percent better than existing capabilities before commercial operators would be interested. On-going design option studies of advanced technology cargo aircraft systems indicate that relative improvements in economics over contemporary systems can be conservatively estimated to exceed 40 percent by the mid-1990s.

We conclude that the development of a civil ACMA with these economic characteristics could greatly benefit sales to both U.S. and international operators. Other significant possibilities include:

- o A much needed stimulation of the air cargo market and the maturity of the air mode of the integrated national transportation system.
- o A larger production program and the potential for reducing unit costs.
- o Attraction of private investors in anticipation of a promising commercial program, with a corresponding reduction in financial exposure of the Federal Government for "en route" funding support.
- o A larger U.S. civilian outsize cargo fleet available for use to meet contingency military augmentation requirements, which could result in a reduction in the size of the military organic intertheater airlift fleets.

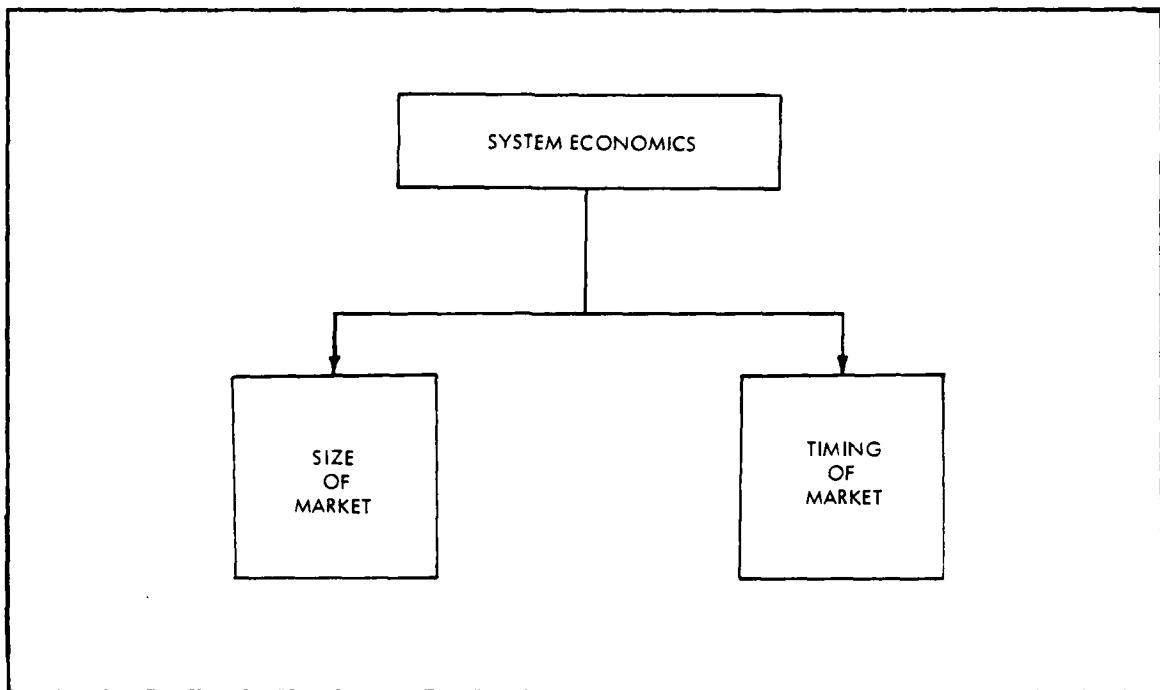


Figure 19. System Economics

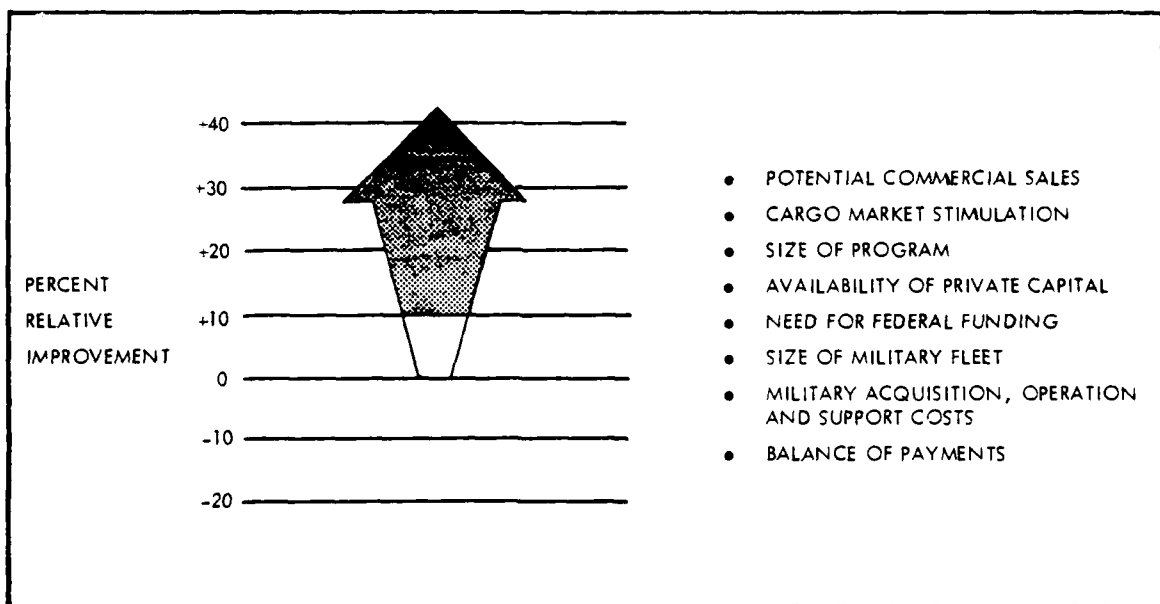


Figure 20. Influence of System Economics on Program Success

- o A smaller military fleet size which should significantly reduce the overall strategic airlift system acquisition, operation, and support costs.
- o A potential volume of sales to international users which should contribute to improving the balance of payments.

PROGRAM INTERRELATIONSHIPS

The integration of the preceding discussions pertaining to military and civil need derivation, system definition, and system economics is shown in Figure 21 to portray the various interrelationships. It is important to note that the better the relative economics of a new ACMA system, the more attractive it will be to the civil sector and the higher the probability of obtaining private financial participation. This would undoubtedly have great appeal to Congress and to the public in gaining acceptance for initiation of the program. Conversely, the poorer the relative improvement in system economics, the less appeal it may have to civil interests; thus, major government funding support may be required for the overall program.

REPRESENTATIVE OPERATIONAL PROGRAM

The minimum military needs, represented only by the C-141 fleet phase-out, and the civil market projection for large cargo aircraft, as previously discussed, have been combined with the results reflected in Figure 22. The time span covered begins with an assumed initial ACMA production delivery date of 1994 as derived from the representative program planning schedule and goes to the year 2010. The projected replacement of the C-141 fleet—1998 to 2004—is shown in the shaded area. Since replacement of the C-5 fleet is not currently programmed to begin until 2012, it is not shown. In order to maintain the same equivalent military airlift capability in total ton-miles-per-day for the C-141 fleet, 44 ACMA aircraft would be phased into the organic military inventory during the same time period. The production rate shown at the bottom of the figure is the rate necessary to meet the combined military and commercial needs. Cumulative deliveries are also indicated.

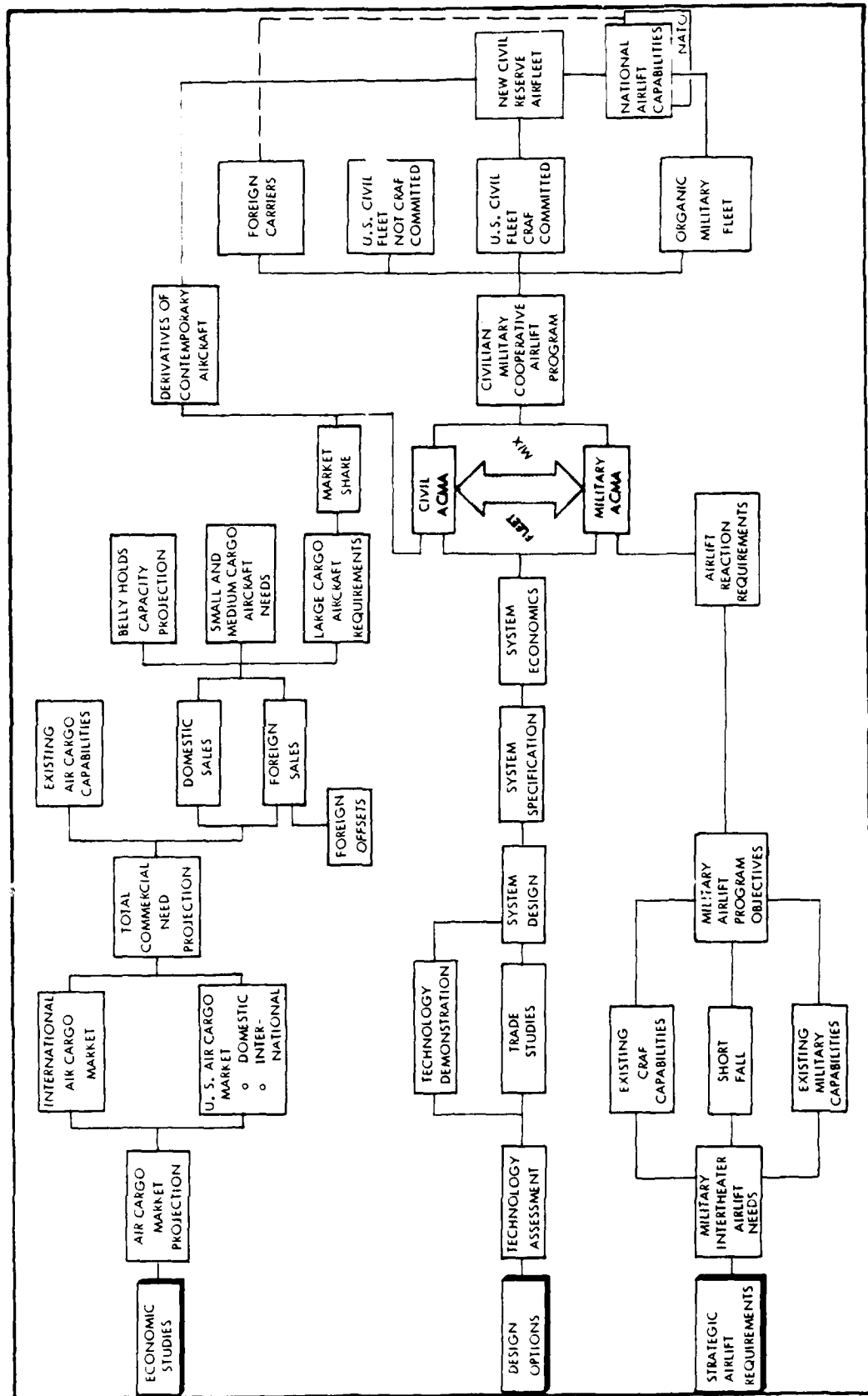


Figure 21. Program Interrelationships

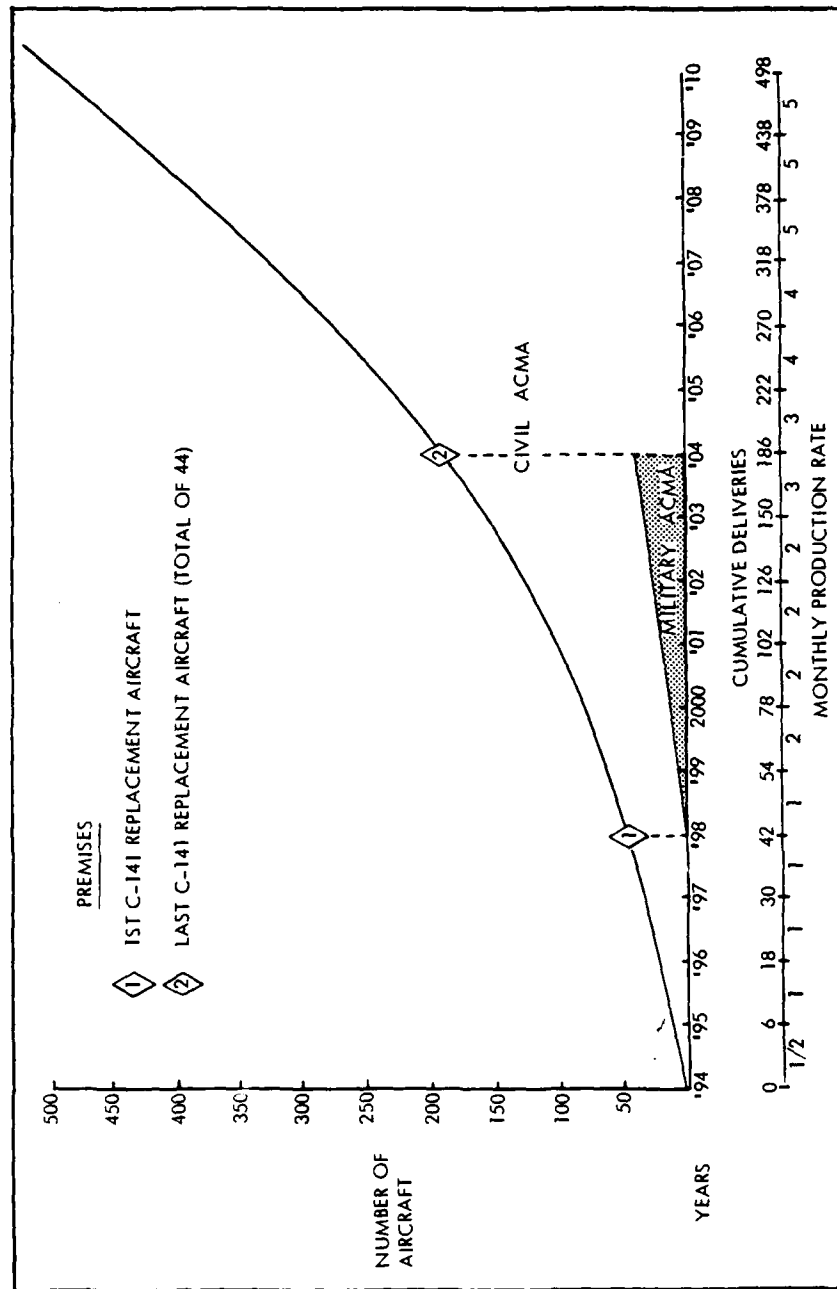


Figure 22. Representative Operational Program

As can be seen, approximately 42 ACMA aircraft could be available for use within the civil sector prior to the program need date for the initial C-141 replacement. However, the possibility of an increased threat to our world-wide national interests or increased funding pressures resulting from organic fleet obsolescence, and could create a need for earlier deliveries to the military to satisfy organic airlift mission requirements.

FLEET MIX CONCEPT

As noted, it is a widely accepted premise among those contacted that the government would provide funding for the research and development phase of the proposed joint civil-military development program. This is based on the magnitude of the funds which would be required and the general recognition that the primary stimulus for such a program is the national defense needs for improving our emergency airlift capabilities to meet contingency requirements anywhere in the world.

The commercial need is not as readily apparent because the total requirement for large cargo aircraft is not consolidated in one customer as is the military need. As discussed elsewhere in this report, there is not a perceived need at this time for large quantities of these aircraft to satisfy the early commercial requirements. The initial demand can be characterized as the integration of small numbers, on the order of one to ten per carrier. Based on the small number of aircraft required by civil operators, the validity of the combined need must be highly convincing for Congress and the public to conclude that a joint program is in the best interest of the nation. Because of the relatively small quantity of aircraft with these unique capabilities that will be needed to satisfy early civil needs, it appears that it may be necessary for the government to provide production funding initially for more aircraft than they need in the organic fleet. This assumption is based on the fact that the civil market demand is small at the outset and will experience a slow growth rate during the early production period.

Based on this assumption, it may be advantageous to all concerned for the government to purchase those aircraft needed to launch the program, then lease all aircraft in excess of "hard-core" military needs to commercial operators.

Lease terms might be based on utilization (i.e., ton-mile/flight hour or similar cost formula). Basic to such arrangements might be the desirability to impose operational constraints on these resources in order to assure their availability to meet short-notice national emergency needs. Incentive adjustments to compensate for such arrangements would appear to be both desirable and necessary. These government-owned, airline-leased aircraft might provide a basis for amendments to the Civil Reserve Air Fleet (CRAF) concept. It is conceivable that these aircraft could be maintained in militarily-compatible operational configurations, and thus be more "time responsive" in an emergency than current CRAF resources. If feasible, such arrangements could result in a reduction in the size of the organic military fleet.

A fleet mix concept, illustrating three possible readiness postures for an initial production quantity of 96 aircraft, is shown in Figure 23. As indicated in this example, it might be necessary for the government to purchase the first 48 aircraft to initiate the program. One squadron of organic aircraft (16 aircraft) might be maintained in a continuous alert posture. The other 32 government--owned aircraft might be leased under the conditions that they must be made available to meet military contingency requirements within a relatively short period (for example, within 18 hours after notification). The other aircraft operated by U.S. carriers would be available within 24 hours, the same as current CRAF procedures.

Additional study is required to more completely assess the many influences and trade-offs surrounding this important issue and its eventual impact on program success.

FINANCIAL PLANNING

The detailed financial plan discussed in this report is structured around three phases: the conceptual phase, the validation phase, and the development phase. The organization of these phases is patterned after government procurement policies which, because of their completeness, produce a more coordinated overall plan. In the following paragraphs each phase is addressed separately. For each phase the action required is described, the agencies or

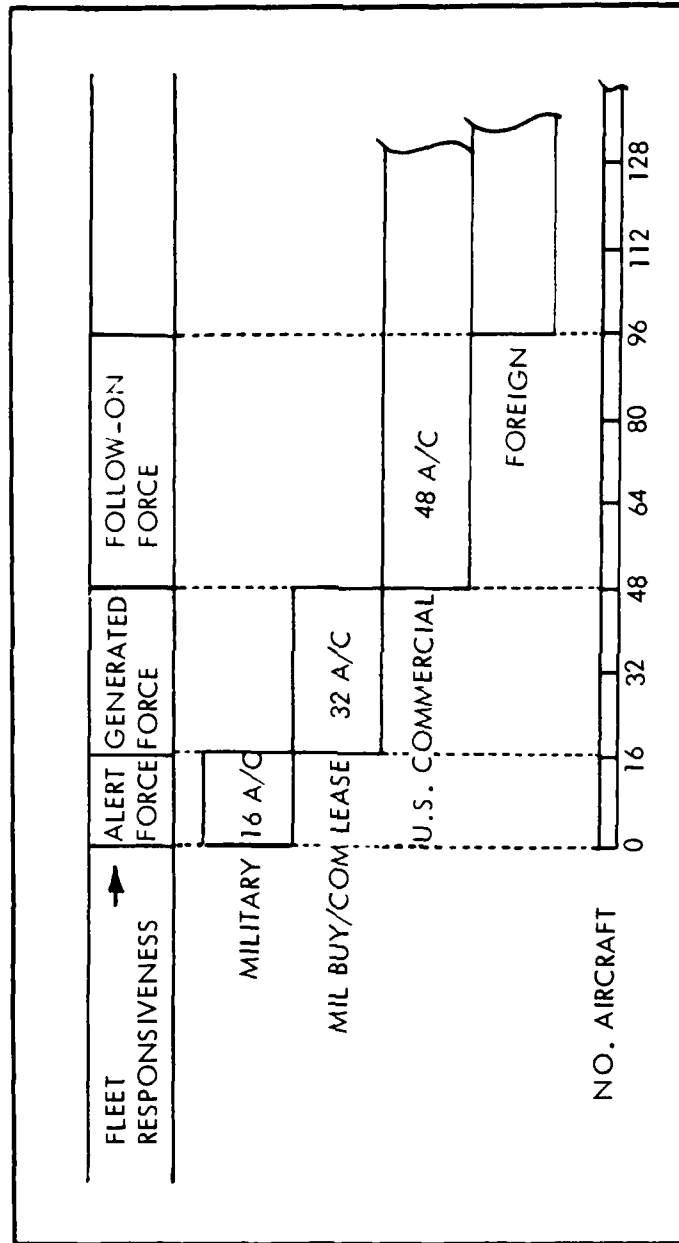


Figure 23. Fleet Mix Concept

organizations that appear to be most capable of taking the action are identified, and the other participants in the action are indicated. Following this, the funding concepts for the phases are discussed.

As noted above, the system development phases are discussed in terms of Office of Management and Budget A-109 procedures. Depending on the interim management technique selected and the program management system designed during the validation phase, other programs could possibly be developed. For any logical program plan, it is reasonable to expect that most of the elements discussed in this report will be applicable.

Conceptual Phase

During this critical period, comprehensive studies covering economic, technical, and military aspects of the program would be initiated under the sponsorship of the appropriate government agency having primary statutory responsibility over such matters. The outputs of these efforts will provide the necessary basis for establishing alternative concepts, including estimated operational, schedule, procurement, cost, and support parameters. A representative listing of these and other related activities is shown in Figure 24 along with an identification of those government agencies (in order of possible responsibility) which might be expected to actively participate in a managerial or coordinating role in the accomplishment of each.

Since the driving force for pursuing a cooperative development concept is based on a fundamental requirement to provide augmentation of our outsize emergency airlift capability, all funding for conceptual phase activities would be provided by the government. Manufacturers can be expected to bear the costs of preparing proposals responsive to study tasks outlined in government agency solicitations. It is not expected that major carriers will provide funding support during this phase. They can however, be expected to offer non-reimbursable, planning staff support in the accomplishment of study tasks on an ad hoc basis.

CIVILIAN/MILITARY COOPERATIVE AIRLIFT SYSTEM DEVELOPMENT

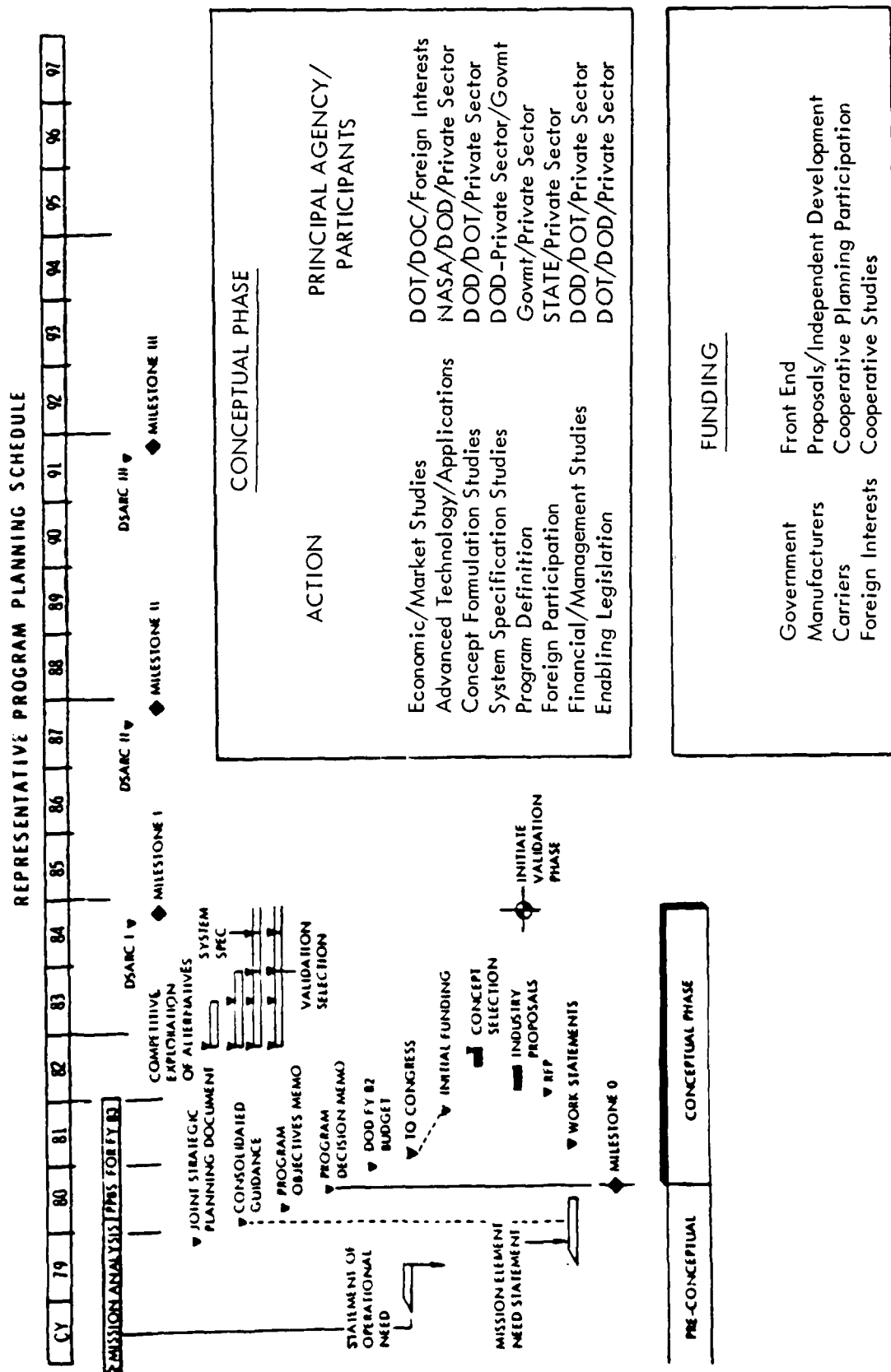


Figure 24. Representative Conceptual Phase

Validation Phase

The refinement of major program characteristics will be completed during the validation phase. In order to validate the choice of alternatives, extensive study and analysis, hardware development, test and evaluation will be accomplished in preparation for the initiation of the detailed system design. Major developmental activities are indicated in Figure 25. The development of policy guidance and specific provisions covering possible foreign participation has been suggested as a potential action for the Department of State. Other executive agencies would have major interests and responsibilities in this area. Program Management arrangements may undergo a transition during this phase to accommodate the increasingly more active participation by civil interests in major decisions covering system design.

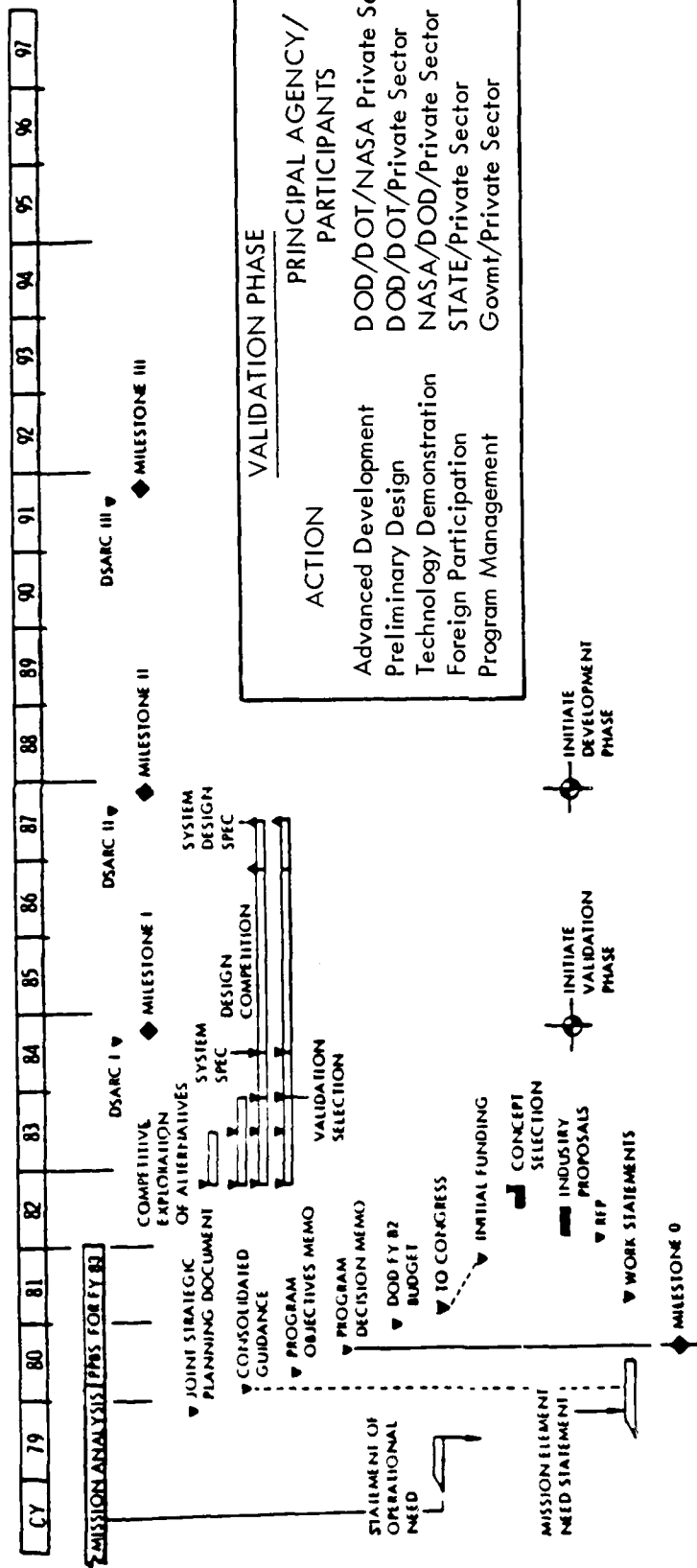
We anticipate that the Federal government would provide the primary source of funds during this phase. Based on the premise that the principal design objective is the production of an advanced technology cargo aircraft with improved direct operating costs and fuel efficiencies to satisfy future demands of the air cargo market, it is reasonable to expect that funding support may also be provided by manufacturers, U.S. carriers, and international interests if the final design offers a significant competitive advantage in system economics over existing transport aircraft and derivatives of contemporary transport aircraft.

Development Phase

Major actions to be undertaken in the full-scale engineering development (FSED) phase include the start of detailed design of the system as shown in Figure 26. Principal items necessary for the system's support are also designed, fabricated, tested, and evaluated during this period. A pre-production system may also be produced. Program management and decision responsibilities would probably be jointly shared by the government and the private sector because of their common interest in the final product.

CIVILIAN/MILITARY COOPERATIVE AIRLIFT SYSTEM DEVELOPMENT

REPRESENTATIVE PROGRAM PLANNING SCHEDULE



| VALIDATION PHASE | |
|--------------------------|--------------------------------|
| ACTION | PRINCIPAL AGENCY/ PARTICIPANTS |
| Advanced Development | DOD/DOT/NASA Private Sector |
| Preliminary Design | DOD/DOT/Private Sector |
| Technology Demonstration | NASA/DOD/Private Sector |
| Foreign Participation | STATE/Private Sector |
| Program Management | Govmt/Private Sector |

| FUNDING | |
|-------------------|------------------------|
| Government | Primary Source |
| Manufacturers | Contributor* |
| Carriers | Contributor* |
| Foreign Interests | Potential Contributor* |
| | *Design Dependent |

| PRE-CONCEPTUAL | CONCEPTUAL PHASE | VALIDATION PHASE |
|----------------|------------------|------------------|
|----------------|------------------|------------------|

Figure 25. Representative Validation Phase

CIVILIAN/MILITARY COOPERATIVE AIRLIFT SYSTEM DEVELOPMENT

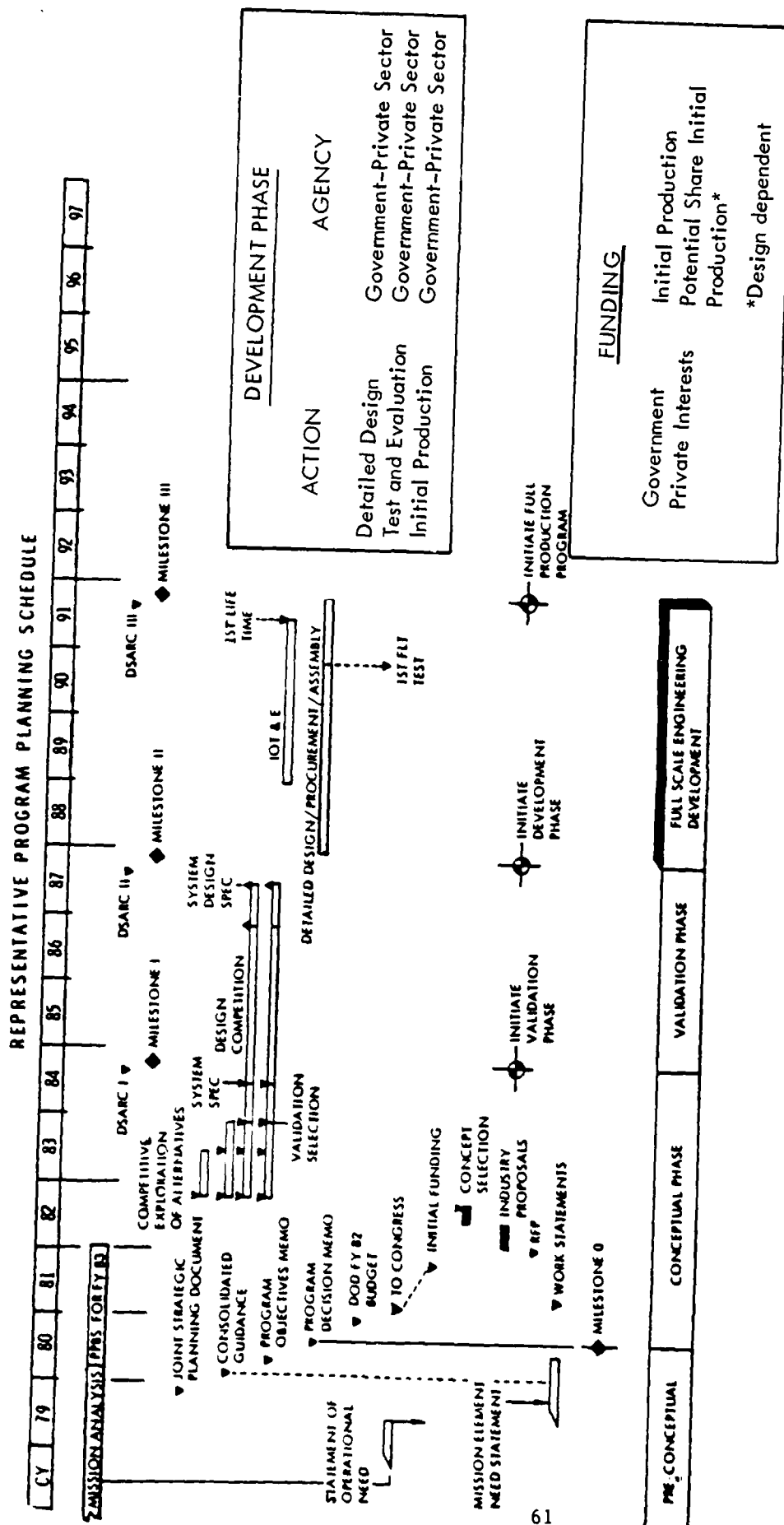


Figure 26. Representative Development Phase

In view of the uncertain early quantitative demand within the civil sector, FSED funding may have to be provided by the government. If the economic characteristics and resultant potential market attractiveness of the new system are sufficiently better than existing, or derivative transport designs, civil carriers may be induced into placing advanced payments for early delivery positions.

IV. ENERGY CONSIDERATIONS THAT MAY IMPACT THE PROGRAM

Beginning with a discussion of conventional and alternate fuels, we investigated various energy considerations related to engines suitable for an ACMA in the 1990s, energy savings for commercial air cargo carriers, and the impact of new aircraft on strategic airlift from an energy viewpoint. A brief description of the possible effects of two aerodynamic design improvement concepts on airplane efficiency completes this section.

AVAILABILITY OF CONVENTIONAL FUELS

To fully understand the future of strategic airlift and commercial air cargo from an energy viewpoint, one must first visualize how these two fit into the total U.S. energy consumption picture. All transportation modes combined account for about 26 percent of the total energy consumed by the United States. Unfortunately, transportation is very heavily dependent on petroleum for its energy, accounting for about 54 percent of all U.S. petroleum consumption.

Perspective

Figure 27 shows how each barrel of oil consumed in the United States was divided into its end uses in 1977. Note that 9.8 per cent of all transportation fuels was used by aviation, or 5.3 percent of the total barrel. Of this aviation share, the Air Force used about 23 percent, or 1.2 percent of the total. Strategic airlift accounts for about 27 percent of the Air Force's consumption, which is only 0.3 percent of the total U.S. petroleum consumption (Reference 15 and 16).

Figure 27 also portrays commercial air cargo's relative share of the barrel. Note that, today, air cargo accounts for less than one tenth of one percent of the total U.S. petroleum consumption.

Despite their relatively small fraction of the demand, the airlines and the military have already established an impressive record of conservation since the 1973-1974 oil embargo. For example, U.S. scheduled airlines actually used

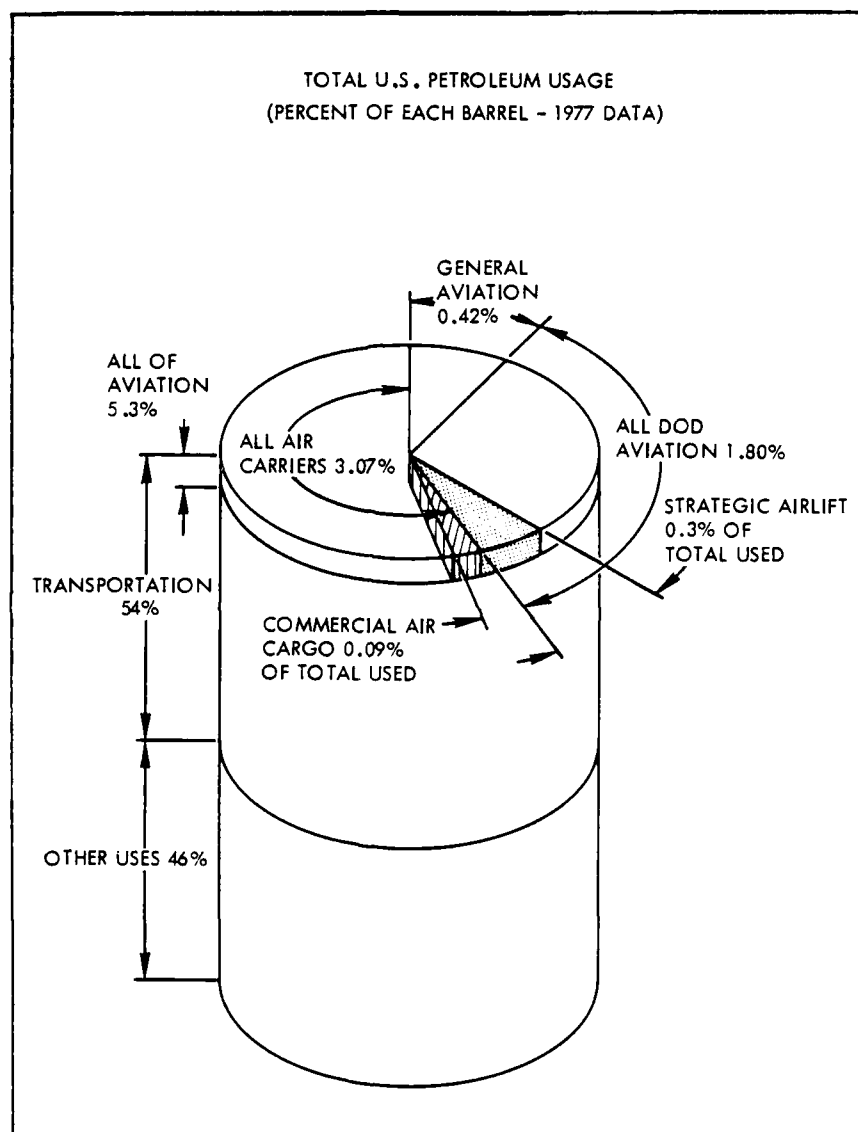


Figure 27. Commercial Air Cargo and Military Strategic Airlift Petroleum Usage

800 million gallons less fuel in 1976 than in 1973 while carrying 21 million more passengers. While other consumers have demanded larger quantities of fuels, aviation has held the line. In fact, the increase in gasoline consumption alone from 1970 to 1976 exceeded the total jet fuel consumed by all aviation in 1976 (Reference 16).

Long Range Projections

For this analysis, the period 1990 through 2025 was selected because 1990 represents the earliest initial operational capability for a new cargo aircraft and 2025 would approximate its phase out. Numerous studies have been conducted to determine oil supplies and demand through the year 1990, but few estimates are available beyond 1990.

Figure 28, based on Reference 17, displays the forecasted U.S. demand for liquid fuels through the year 2000 for a medium growth scenario. Most of the deficit between total demand and U.S. supplies will initially be filled with imports. If the government holds imports to 8.2 million barrels per day (MMB/D), however, alternative energy sources, along with conservation efforts in all sectors of transportation, will be required after 1985 to satisfy total demand.

M. K. Hubbert, energy consultant and retired Senior Scientist at the U.S. Geological Survey, has suggested that like all non-renewable natural resources, oil production tends to follow a bell-shaped curve like that shown in Figure 29. Our domestic petroleum production rate peaked on such a curve in 1970 (Figure 30) and has since been declining at a rate of 3 percent per year (References 15 and 18). By the year 2000, U.S. domestic oil production is expected to account for less than 10 percent of the world's production.

Total ultimate world oil resources have been variously estimated at 1600 to 2300 billion barrels with a mean expected supply of around 2000 billion barrels (References 17, 19, and 20). Figure 31 superimposes the energy cycles for the world oil supply, the world coal supply, and the world oil shale supply with the U.S. domestic oil cycle. For the sake of comparison they have been expressed in terms of quadrillion BTU's (quads). One can see that world

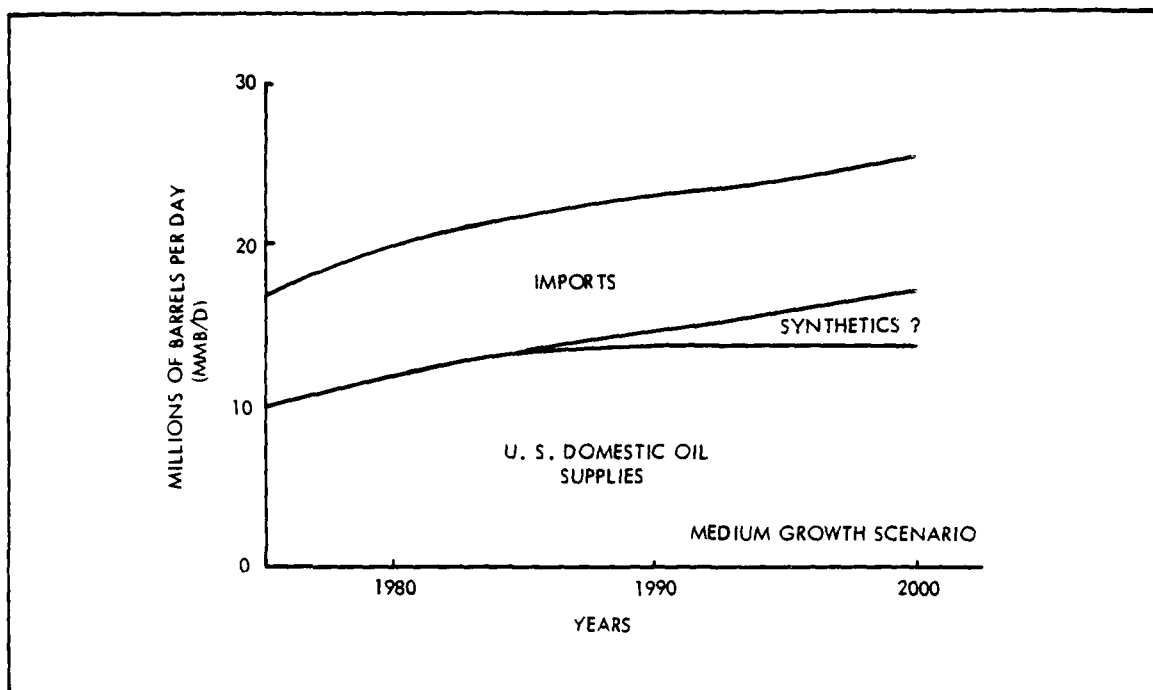


Figure 28. Total U.S. Liquid Fuels Demand

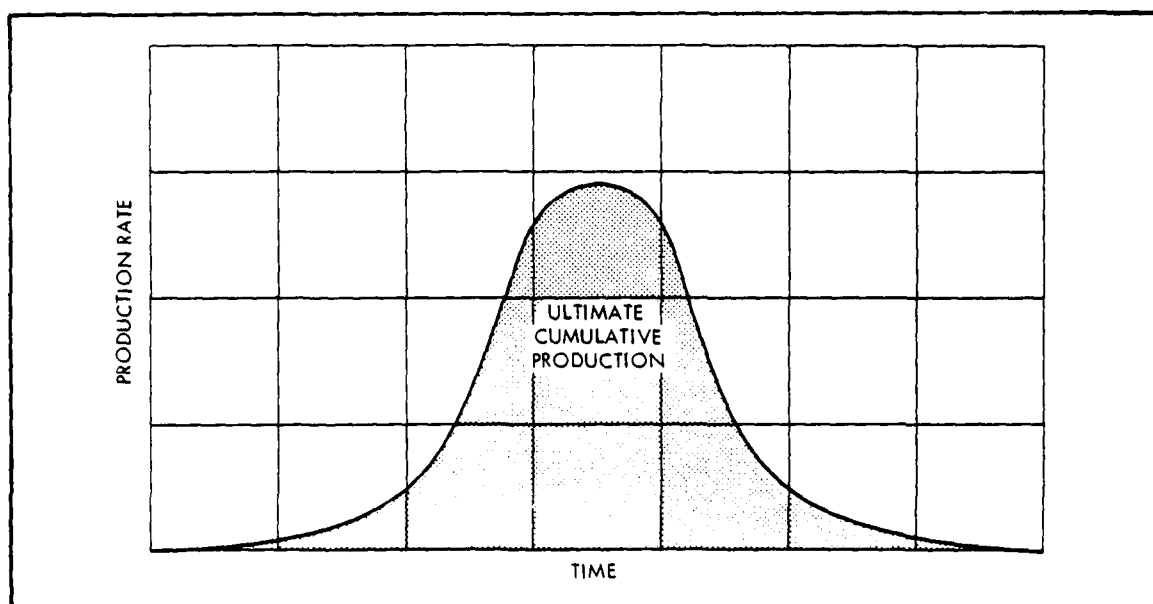


Figure 29. A Typical Production Curve for a Non-Renewable Resource

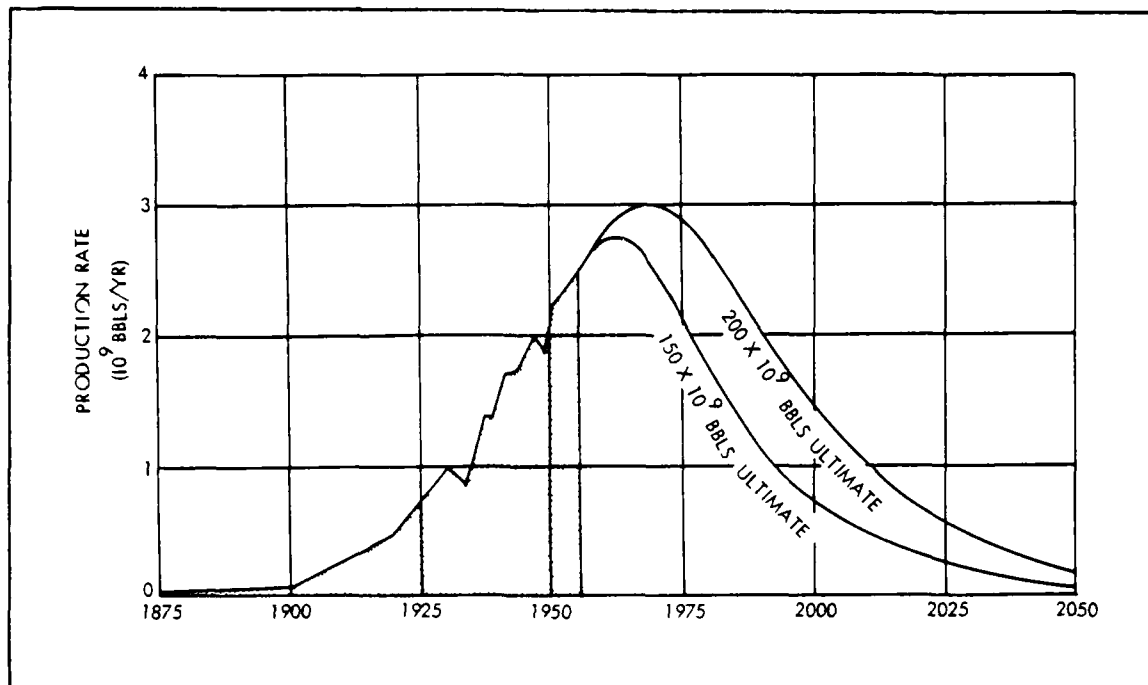


Figure 30. U.S. Domestic Crude Oil Production Cycle

Source: Reference 21

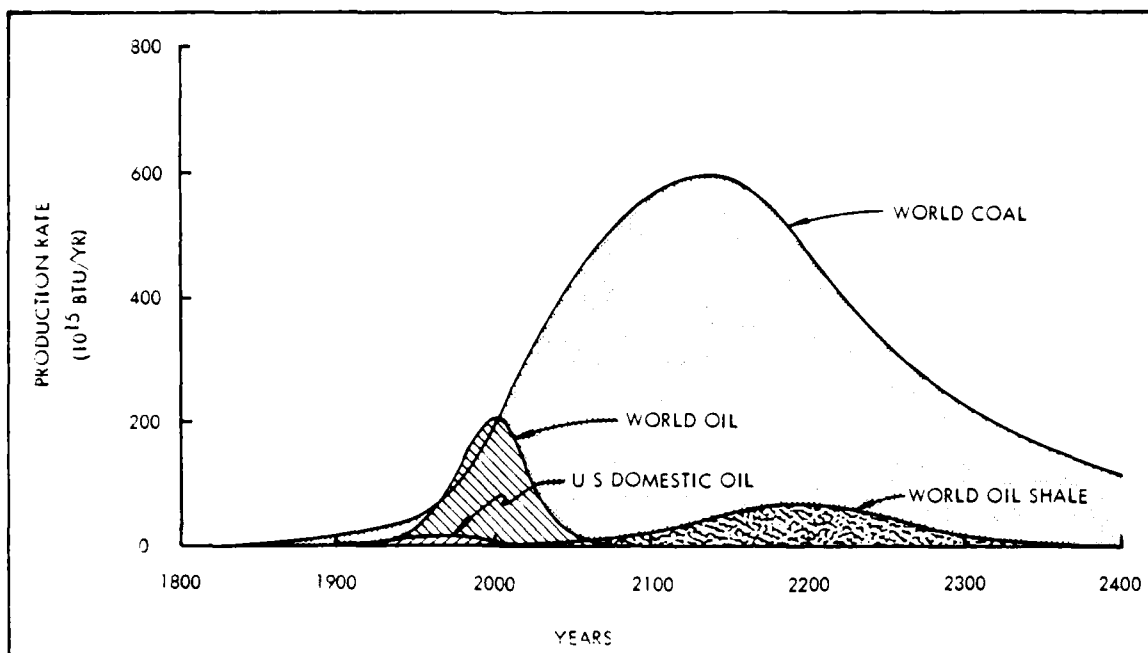


Figure 31. Comparative Energy Production Cycles

oil production will peak sometime between 1995 and 2000 based on present technology (Reference 21).

The above estimates of world oil resources amount to a 30 year supply of petroleum. At the end of this period supplies will not abruptly run out; rather, production rates will gradually decrease and prices will increase until a point is reached where alternate energy sources will become economically competitive.

DOE Allocation Policies

While the transition from petroleum to synthetics is occurring, fuel supplies will become scarce, perhaps necessitating fuel allocations. Officials of the Economic Regulatory Administration of the Department of Energy state that present DOE policy is to establish no future allocation regulations. Further, no priority is likely to be established for aviation over surface modes of transportation (Reference 22). But since policies of the DOE are subject to broad change, long-range policy predictions are not possible.

A set of standby allocation regulations still exists (Federal Register, January 18, 1979, pp. 3928-3942). Briefly stated, these standby regulations allocate one hundred percent of current fuel requirements to the Department of Defense and domestic, supplemental, and scheduled cargo air carriers. There are also provisions within the regulations to cut back on industrial and utility uses of kerosene-based jet fuels and middle distillates such as diesel fuel and kerosene.

Turbine Fuel Distillation and Fuel Types

A few basic terms need to be explained at this time. Crude petroleum, as it comes from the well, is a mixture of many different types of hydrocarbons. In the refinery, this crude is heated to boiling and then piped to a distillation tower. There, the lightweight hydrocarbons rise to the top of the tower and are condensed and drawn off. Progressively heavier hydrocarbons behave similarly, but condense at lower levels within the tower. From the top of the tower, methane and butane are drawn off, followed by gasoline, diesel fuel, kerosene, bunker oil, lubricating oil, and residual oil.

Diesel fuel and kerosene make up what are known as the middle distillates. Jet fuels are blends from this group of distillates which include some gasoline and some heavier oils. The range of hydrocarbons selected for this blending determines the "cut" of the fuel. Wide-cut fuels are blended from a wide range of hydrocarbons; narrow-cut fuels include only a small range of hydrocarbons from the distillation tower.

Commercial fuels are classified as Jet A, Jet A-1, and Jet B. The first two are narrow-cut kerosene-based fuels with only slightly different specifications. Jet B is a wide cut fuel.

The most common military petroleum fuels are JP-4, JP-5, and newly developed JP-8. JP-4 is a wide-cut fuel used extensively by the Air Force. JP-5, a narrow-cut fuel, was designed specifically for hazardous areas such as aboard aircraft carriers. JP-8 was developed by the Air Force so that refiners might produce slightly larger proportions of jet fuel and the Air Force could standardize its fuel world wide. It is similar to Jet A-1 with additives to control icing and corrosion.

Competition for the Middle Distillate Fuels

With very little additional processing, one middle distillate can be converted into another. It is foreseeable that the Department of Energy, in an attempt to alleviate a heating-oil shortage, might require that refineries shift their production mix to produce more heating oil. Decisions of this nature, made without a full appreciation of their impact, could have adverse affects on jet fuel supplies.

Impact of Diesel Fuel Demand on Jet Fuel Supplies

There is some concern now that, with the proliferation of diesel-powered vehicles, that the demand for diesel fuel will affect future supplies of jet fuel. For the period 1975 to 2000, consumption of diesel fuel has been forecast to grow at a rate of 5 percent per year, the highest growth rate of all the transportation fuels; however, this figure is lower than the historical growth of 7.4 percent per year (Reference 23). Demand projections for the other transportation fuels are compared with diesel fuel in Figure 32 and Table 2.

TABLE 2

GROWTH IN THE DEMAND FOR TRANSPORTATION FUELS
1947 To 1975 Versus 1975 to 2000

| Fuel Type | Average Annual Growth (Percent) | |
|---------------|---------------------------------|---------------------------|
| | Historical 1947 to 1975 | Projected 1975 to 2000 |
| Diesel | 7.4 | 5.0 |
| Gasoline | 4.1 | -1.5 |
| Jet Fuel | 5.2 ^a | 3.7 |
| Bunker Marine | -0.2 | 3.4 |

Source: Reference 23

^aThe historical period is 1965 to 1975

The significant figure to observe in Table 2 is the decline in projected gasoline demand after 1980 due to an overall improvement in fuel efficiency for the automobile fleet. This decrease in gasoline consumption allows refiners to shift their product mix and thereby produce more middle distillates such as jet fuel and diesel fuel.

Fuel Specification Changes

Much discussion has centered around changing fuel specifications in order to increase jet fuel supplies in the near-term. Presently, the American Society for Testing and Materials (ASTM) sets the fuel specification standards for the industry. Basically, there are three specifications that might be adjusted in order to obtain slightly increased fuel supplies:

- o Flash point
- o Freeze point
- o Aromatic content

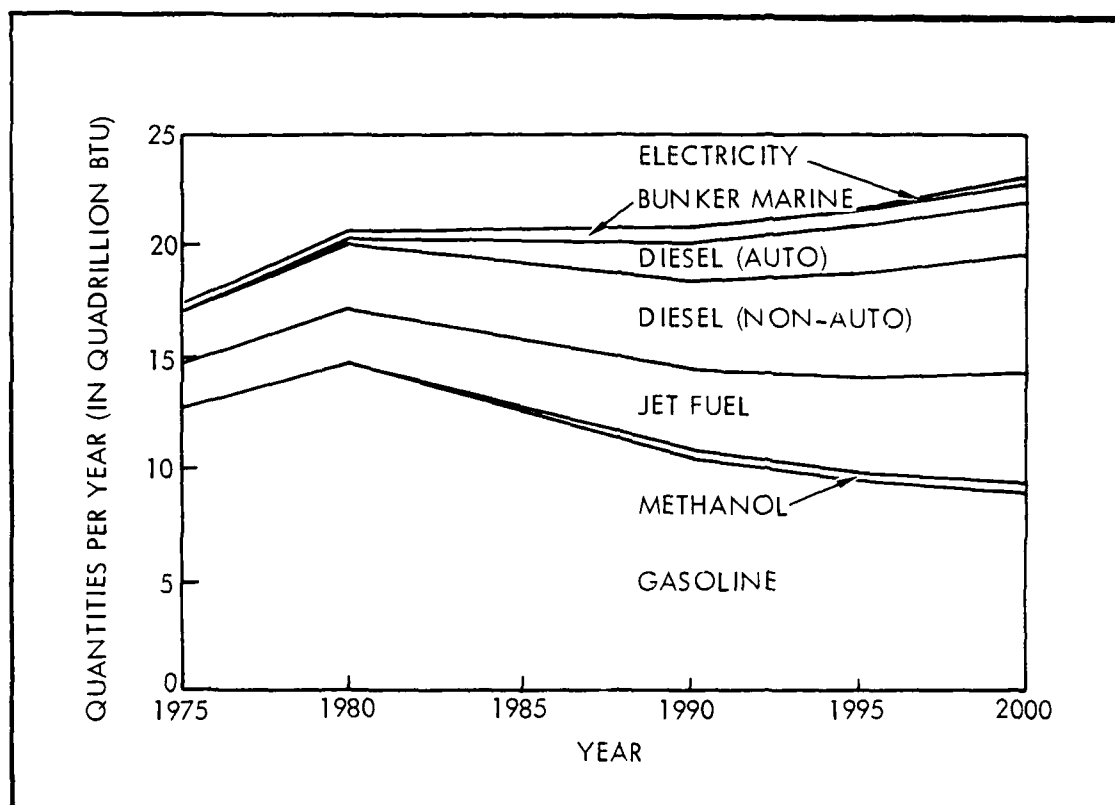


Figure 32. Forecast Consumption of Energy Products in the Transportation Sector, 1975 to 2000 Medium-Growth Scenario

Minimum flash point for jet fuel is currently set at 38°C (100°F). It has been suggested that this be lowered to 27°C (80°F); however, the increased risks of fire adversely affect ground handling safety.

Freeze point is the temperature at which waxes in the fuel begin to solidify. These solids make the fuel difficult to pump and also clog fuel lines. The maximum freeze point is now set at -50°C (-58°F). It has been proposed to raise this to -29°C (-20°F), a move which would necessitate fuel heating on board the aircraft. Sources within ASTM indicate that this change is not very likely (Reference 24).

Turbine fuels contain varying amounts of paraffins, naphthenes, and aromatics. Compared to the first two hydrocarbons, aromatics contain about half the hydrogen. Because of this, they limit the energy content of the fuel, form large deposits of soot, and cause higher flame temperatures in combustors. ASTM has set the limit at 20 percent aromatics. A limit of 35 percent has been proposed to allow the use of synthetic fuels from coal. Some tradeoffs will probably be required between higher aromatic levels and increased maintenance.

Fuel Outlook

To summarize, thus far, the following conclusions can be made.

Civil and military air cargo use only a small fraction of the total U.S. domestic demand for liquid fuels. Unfortunately, they are almost totally dependent on petroleum. Being such a small segment of the market, they have little control over the types of fuel available.

Petroleum-based fuels will become increasingly scarce throughout the lifetime of this joint program. As this happens, fuel costs will escalate, thereby placing greater emphasis on fuel-efficient aircraft and making alternative fuels economically feasible.

DOE policies are extremely short-term oriented, but currently there are no plans to allocate transportation fuels or to establish priorities among the various transportation user segments.

In the 1990s, the increased demand for automotive diesel fuel will be more than offset by substantial reductions in gasoline consumption, which will allow refiners to produce greater quantities of diesel and jet fuel.

It is unlikely that changing fuel specifications will significantly increase fuel availability. Any further changes in specifications could have adverse effects on engine life and performance.

AIRCRAFT FUEL ALTERNATIVES

Although many alternative energy sources have been proposed, the transportation sector, and especially aviation, is limited to only a few usable choices.

Any aviation fuel must have a high heat content per pound because of weight constraints. On the other hand, the volume of fuel required to achieve a particular range must not be excessive or there will be drag penalties and loss of payload space. Furthermore, the environment in which an aircraft operates requires the fuel to be usable throughout a wide temperature range. Table 3 compares some candidate fuels.

Liquid Hydrogen

A frequently mentioned alternative, liquid hydrogen, is attractive for several reasons (Reference 26). It offers the highest heat content per pound of all the alternatives and it can be produced from water, one of our most abundant resources. Hydrogen is attractive for environmental considerations because it has no carbon-related pollution and its main product of combustion is water. Its cryogenic nature also offers potential benefits when it is used to cool certain engine and airframe parts.

When compared to a conventional petroleum fueled aircraft, the liquid hydrogen aircraft would be lighter with smaller engines, smaller wings, and a larger fuselage. It would be quieter, require shorter runways, and use about one-third the weight of fuel.

TABLE 3
PROPERTIES OF CANDIDATE FUELS

| Fuel | Heat of Combustion | | Density (lb/ft ³) | Boiling Point (°F) | Autoignition Temp. in Air (°F) | Flamability Limits in Air (%) |
|--|--------------------|---------|----------------------------------|-----------------------|--------------------------------------|-------------------------------------|
| | Btu/lb | Btu/gal | | | | |
| Acetylene (C ₂ H ₂) | 20,700 | 100,900 | 38.6 | -119 | 635 | 2.5-80.0 |
| Ammonia (NH ₃) | 8,000 | 45,600 | 42.6 | - 28 | 1204 | 15-27 |
| Ethanol (C ₂ H ₅ OH) | 11,600 | 76,600 | 49.4 | 173 | -- | 3.3-19.0 |
| Hydrazine (N ₂ H ₄) | 7,200 | 60,100 | 62.4 | 236 | 518 | 4.7-100 |
| Jet-Fuel (JP-4) (Naphtha-like) | 18,700 | 121,100 | 48.7 | 210 | 480 | 0.8-5.6 |
| Jet-Fuel (JP-8) (Kerosene-like) | 18,600 | 128,300 | 51.6 | 400 | 450 | 0.6-5.0 |
| Liquid Hydrogen (LH ₂) | 51,600 | 30,400 | 4.4 | -423 | 1085 | 4.0-74 |
| Liquid Methane (LCH ₄) | 21,500 | 74,400 | 25.9 | -259 | 1000 | 5.0-15 |
| Methanol (CH ₃ OH) | 8,600 | 58,100 | 50.5 | 149 | 867 | 6.7-37 |
| Monomethylamine (CH ₃ NH ₂) | 13,500 | 76,700 | 42.5 | 45 | 806 | 5.0-21 |
| Propane (C ₃ H ₈) | 19,900 | 97,100 | 36.5 | - 44 | -- | 2.1-9.4 |
| Gasoline ^a (C ₈ H ₁₈) | 19,100 | 111,800 | 43.8 | 257 | -- | 1.1-7.0 |

^aIncluded for reference only.

There are several disadvantages associated with liquid hydrogen, however. One disadvantage is that new techniques and procedures would be required to handle the fuel and service the aircraft, necessitating substantial capital investment for a new distribution system. Another is its exceedingly low density, requiring about four times the normal tank volume needed for conventional fuel. The biggest problem however, is producing the large volume of hydrogen required for a new aircraft fleet at a price competitive with other fuels.

Presently, most of our hydrogen is made by catalytic steam-reforming of natural gas. Some hydrogen is made by partial oxidation of petroleum hydrocarbons; it can also be produced by coal gasification. All of the above methods are dependent on non-renewable resources.

Electrolysis of water is a cleaner method for producing gaseous hydrogen, but it requires great amounts of electrical energy. Nuclear power could be the source of energy for this process. After hydrogen gas is produced, it must then be liquified. A large amount of energy is again required. Because of the processing energy requirements, liquid hydrogen does not appear to be an economically feasible alternative fuel until well into the next century.

Liquid Methane

Another fuel similar to liquid hydrogen is liquid methane. It, too, is a cryogenic liquid with the next best gravimetric heat of combustion and good combustion qualities. Here again the low density of liquid methane would require large-volume fuel tanks. In the event of a fuel spill, liquid methane does not dissipate as rapidly as hydrogen, and this might constitute a safety hazard.

Liquid methane may be produced by coal gasification, methanation, and then liquefaction. A number of processes are available for gasification although commercial-scale production has not yet been demonstrated. Liquid methane has all the disadvantages of liquid hydrogen, yet very few advantages over conventional jet fuel.

Other Candidates

Among the other possibilities are ethanol, methanol, and ammonia. The first two are liquids at normal temperatures and are fairly easy to produce. In addition, ethanol may be obtained from agricultural products. Ammonia is a liquid at normal temperatures, if stored under slight pressure, and does not require a hydrocarbon energy source to produce it. The biggest drawbacks to these alternatives are their relatively low heats of combustion, a fact which makes them unattractive for aviation uses.

Nuclear fission is occasionally mentioned as an alternative to conventional fuels; however, it lends itself only to certain long-duration military missions. It would not be attractive to the civilian market in a joint program.

Synthetic Fuels

Several times in the past, when petroleum was unavailable, crude oil was synthesized from coal. Once again, serious thought is being given to production of synthetic oil from other carbonaceous sources such as coal, oil shale, and tar sands. This synthetic crude oil can then be processed through existing refineries into its various products.

Fuels derived from oil shale have essentially the same characteristics as our present day aviation kerosene fuels. Coal-derived liquids have chemical characteristics which are appreciably different from existing fuels. These coal derivatives contain much higher percentages of aromatics and sulfur which tend to shorten engine life and degrade performance.

The best alternative fuel for the U.S seems to be oil shale. Once oil shale is converted to liquid form it makes an excellent refinery feedstock. Almost 100 percent of liquid oil shale can then be converted into diesel and jet fuel. It is also the alternative closest to economic success.

Alternative Fuels Outlook

Aircraft of the 1990-2025 era will initially use fuels derived from petroleum. As petroleum becomes more expensive some point will be reached at which it is economically feasible to produce synthetics from oil shale and perhaps coal. At this point we can expect these synthetics to begin replacing petroleum-based fuels.

Commercial production of synthetic oil from tar sands is currently being demonstrated in Canada. The best prospects for the United States seem to lie in oil shale, but its full-scale production has not yet been demonstrated.

Liquid hydrogen will not be available in sufficient quantities for aviation use until after 2010, mainly because the economics of large scale production will not be competitive.

New exotic fuels and technologies require long lead times and large investments. Because of this, it is imperative that the decision maker select the fuels to be used by the next generation of aircraft as soon as possible. The information is available now to make such a decision.

Finally, note that any synthetic industry will probably need some form of government protection if it is to survive. Without this protection, OPEC could crush any venture by suddenly dropping its prices and/or increasing production.

ENERGY CONSIDERATIONS RELATING TO ENGINES FOR THE 1990s

With ever increasing fuel costs and reduced availability, much attention is being focused on improving fuel efficiency in future transport engines. Figure 33 depicts the gradual trend of specific fuel consumption (sfc) for the last thirty years. From 1950 to 1970, sfc was reduced at a rate of about 30 percent per decade. Then from 1970 to the present, sfc was reduced at a rate of about 15 percent per decade.

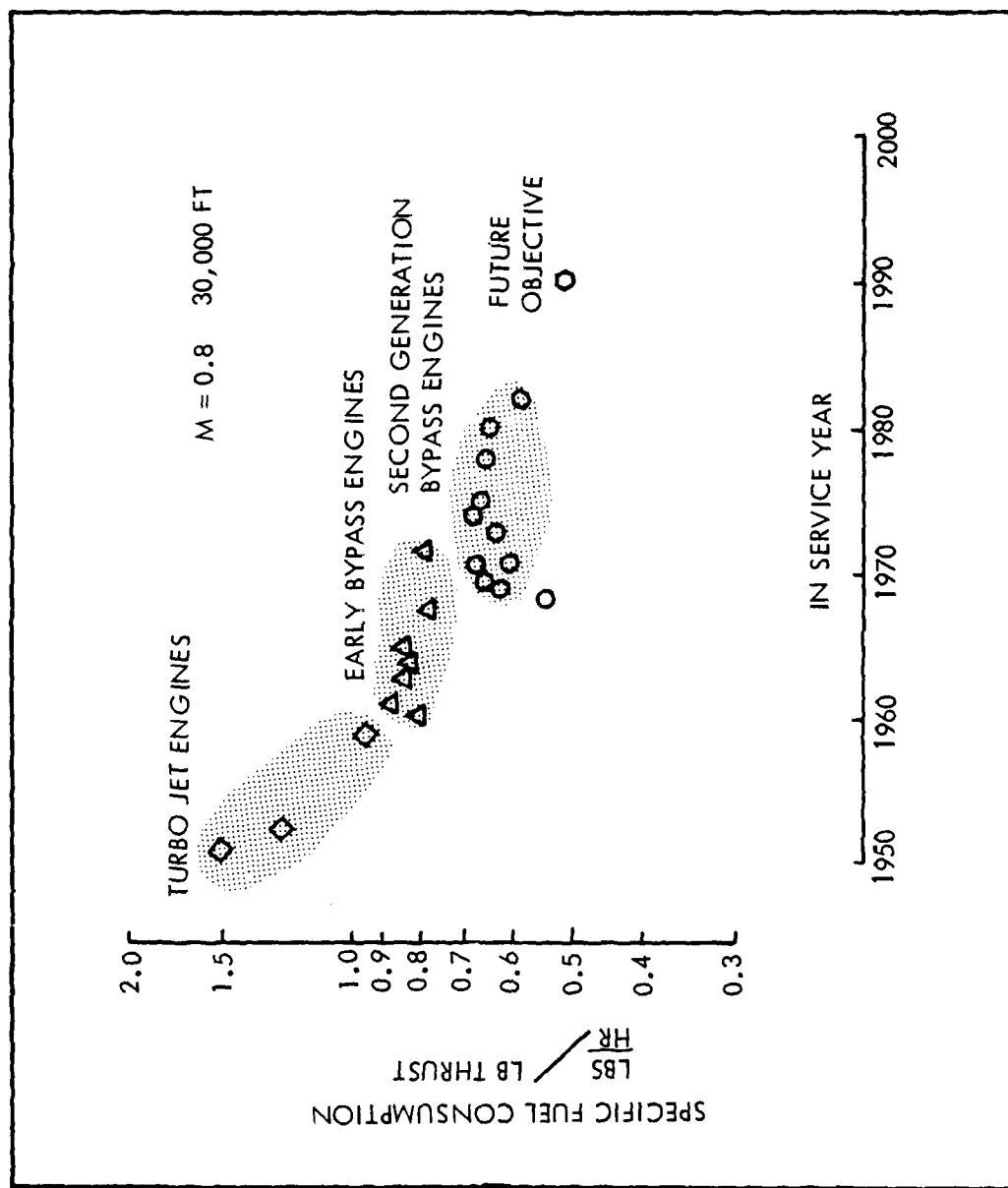


Figure 33. Specific Fuel Consumption Trends for Turbine Engines
Source: Reference 27

In the 1980s, continuing increases in efficiencies will be achieved with modifications and derivatives of current engines. Beyond the late 1980s, sufficient advanced technology could be available to justify a completely new engine.

Continued increases in compression ratios with accompanying increases in turbine inlet temperatures and improved component efficiencies should yield an uninstalled cruise sfc of about 0.55 for the 1990s. By the end of the century, the overall energy efficiency of air transportation may well be twice what it is today.

Figure 34 illustrates improvements that can be made in SFC through increases in the cycle pressure ratio, or through such unconventional concepts as regeneration. Tradeoffs will be necessary between the increased cost and maintenance associated with higher temperatures and pressures, for example, and the added weight and complexity of regeneration (Reference 28).

The Energy Efficient Engine

General Electric and Pratt and Whitney are each developing fuel efficient turbofan technology under NASA's Energy Efficient Engine (E³) project. The project has the following goals:

- o A 12 percent reduction in specific fuel consumption (sfc)
- o A 50 percent decrease in the performance deterioration rate of engines with regard to fuel consumption
- o A 5 percent improvement in direct operating cost

These goals are relative to currently in-service airline transport high by-pass ratio engines, the JT9D-7A and the CF6-50C. The researchers plan to achieve these goals using active clearance controls, single-crystal turbine blades and vanes, new powder metallurgy alloys, a 23:1 compressor, new combustor designs, and digital electronic engine control systems (Reference 29). NASA's objective in this project is to provide an advanced technology base for a new generation of fuel-conservative turbofan engines for commercial transport use.

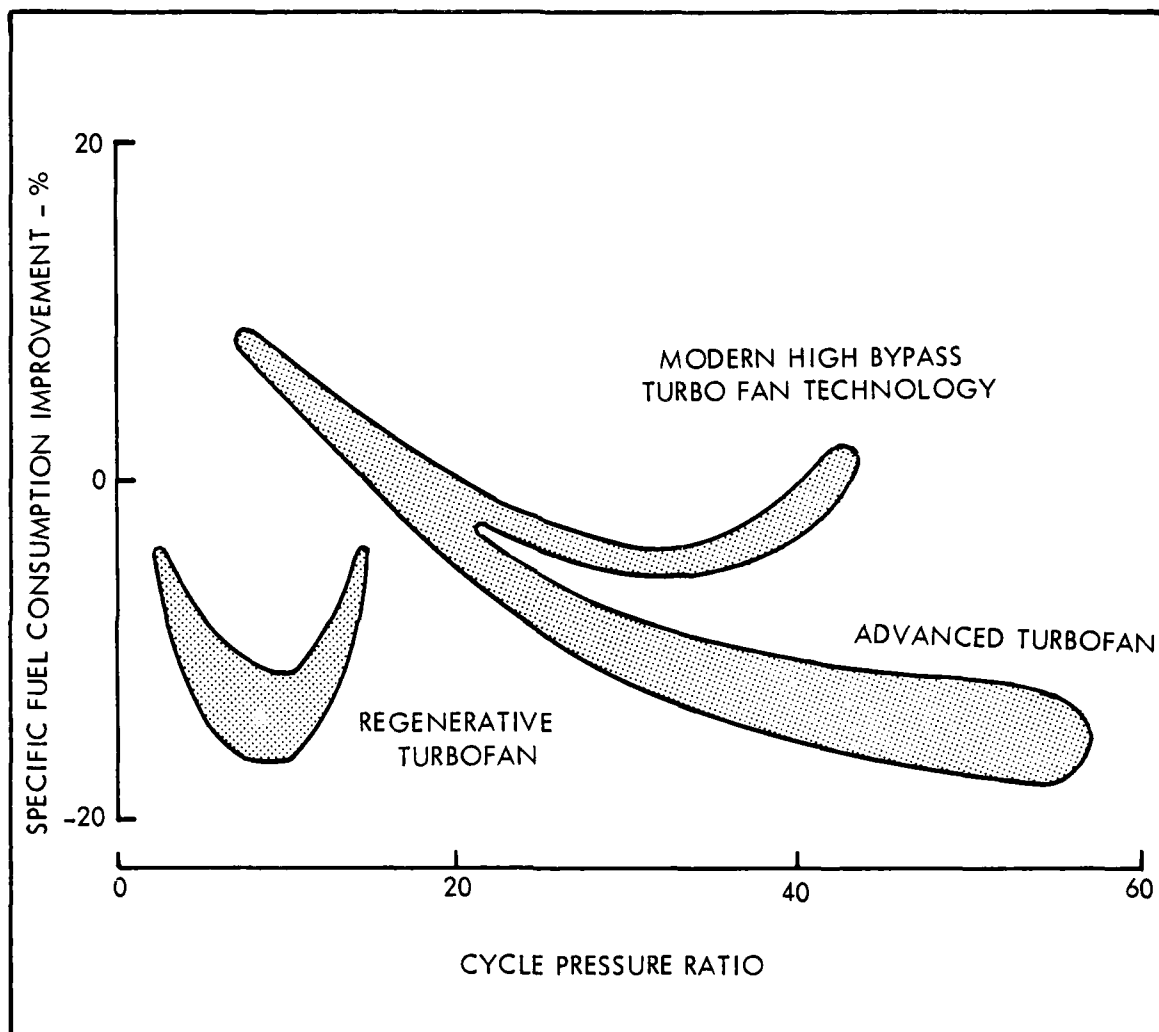


Figure 34: Possible SFC Improvements with Increases in Cycle Pressure Ratio
Source: Reference 28

Effects of Synthetic Fuels on Engines

In addition to operating more efficiently and reliably, the engines of the 1990s must be capable of operating on synthetic as well as conventional turbine fuels. As previously mentioned, coal-derived fuels are expected to contain much higher concentrations of aromatics than present fuels. As a result, the hydrogen contents of these new fuels will be substantially lower than those of present fuels.

Fuels with a higher hydrogen content generally burn more cleanly and easily in engine combustors than fuels with a lower hydrogen content. Increased quantities of soot are generated in the flame zone when the combustor is operated with a low-hydrogen content fuel. This increased soot formation results in higher metal temperatures in the combustor and turbine. In addition, higher nitrogen oxides emission levels result since fuels low in hydrogen burn with higher flame temperatures. These findings indicate that the use of coal-derived liquid fuels may require modifications to current-technology combustors (Reference 18). An alternative is further hydrogenation of the coal-derived liquids with associated increases in costs.

The Advanced Technology Propeller

Along with the E³ studies, NASA has contracted for research into an advanced propeller. This research is currently investigating the critical technology areas of propeller efficiency at cruise Mach Numbers in the vicinity of 0.8, propeller and fuselage noise attenuation, airframe/engine integration, and propeller and gearbox reliability and operating life. The advanced propeller—or prop-fan—along with an advanced turboprop engine, claims to achieve 15 to 20 percent fuel savings relative to similar-technology turbofans with interior noise and vibration levels comparable to current turbofan aircraft (Reference 28). It is intended that prop-fan powered aircraft meet or better FAR field noise standards that have been set in proposed legislation for takeoffs and landings (See Figure 35).

Hamilton-Standard has done the bulk of this research and is confident that a propeller efficiency of 0.80 at 35,000 feet and Mach 0.8 can be achieved.

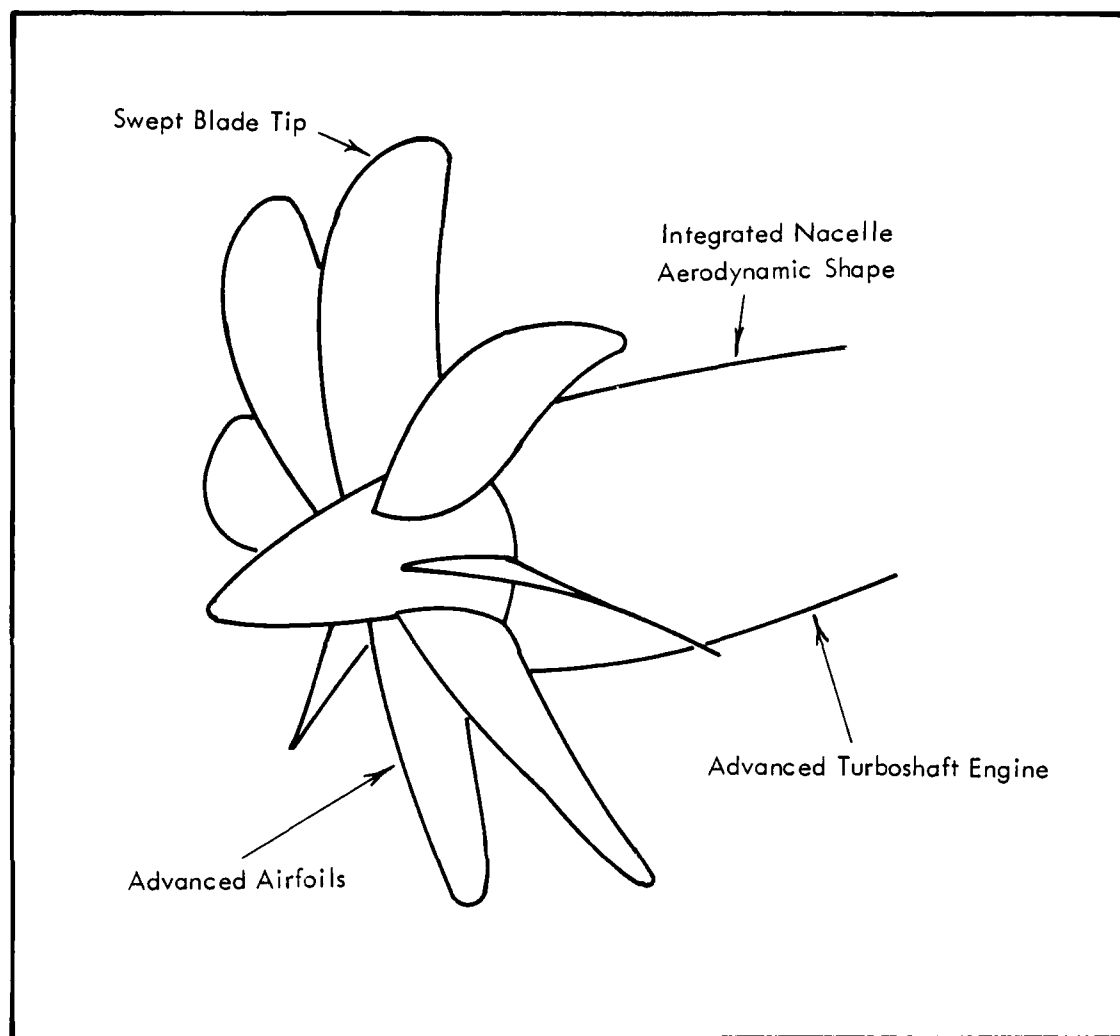


Figure 35. Advanced Technology Propeller
(Reference 30)

Figure 36 shows the propulsive efficiencies possible by incorporating swept blades with advanced airfoils (Reference 30).

There are technical and economics questions to be answered before the prop-fan can be used on a very large cargo transport suitable for both commercial and military roles. At the present, the prop-fan looks most attractive for the short/medium haul markets; however, it must not be ruled out as a possible energy-saving alternative.

The Most Probable Engine for the 1990s

With regard to the most probable engine for the 1990's civil/military transport, we feel that the most likely candidate will be an outgrowth of the E³ project discussed in detail in Section V. Significant improvements in engine cycle efficiency, or possibly new cycle technology, would allow this ACMA to cruise at Mach 0.78-0.80 and 35,000 feet with fuel savings that justify the new engine technology. With relatively small design changes, this new engine would be capable of operating on synthetic as well as conventional fuels without appreciable degradation of performance or reduction in engine life.

Other Considerations

In addition to the research being conducted in alternative fuels and new fuel efficient engines, serious work is being done to explore winglets and laminar flow control.

Winglets are essentially a means of effectively increasing the aspect ratio of the wing. They may or may not be used on future transports, but their greatest potential lies in being retrofitted to existing transports. Fuel savings from this retrofit have been estimated at between 4 and 6 percent.

The concept of laminar flow control (LFC) has been around for a long time. It is a means of substantially reducing drag due to skin friction by means of suction applied to the boundary layer air flow. This would involve literally thousands of holes in the skin of the aircraft and the necessary plumbing to

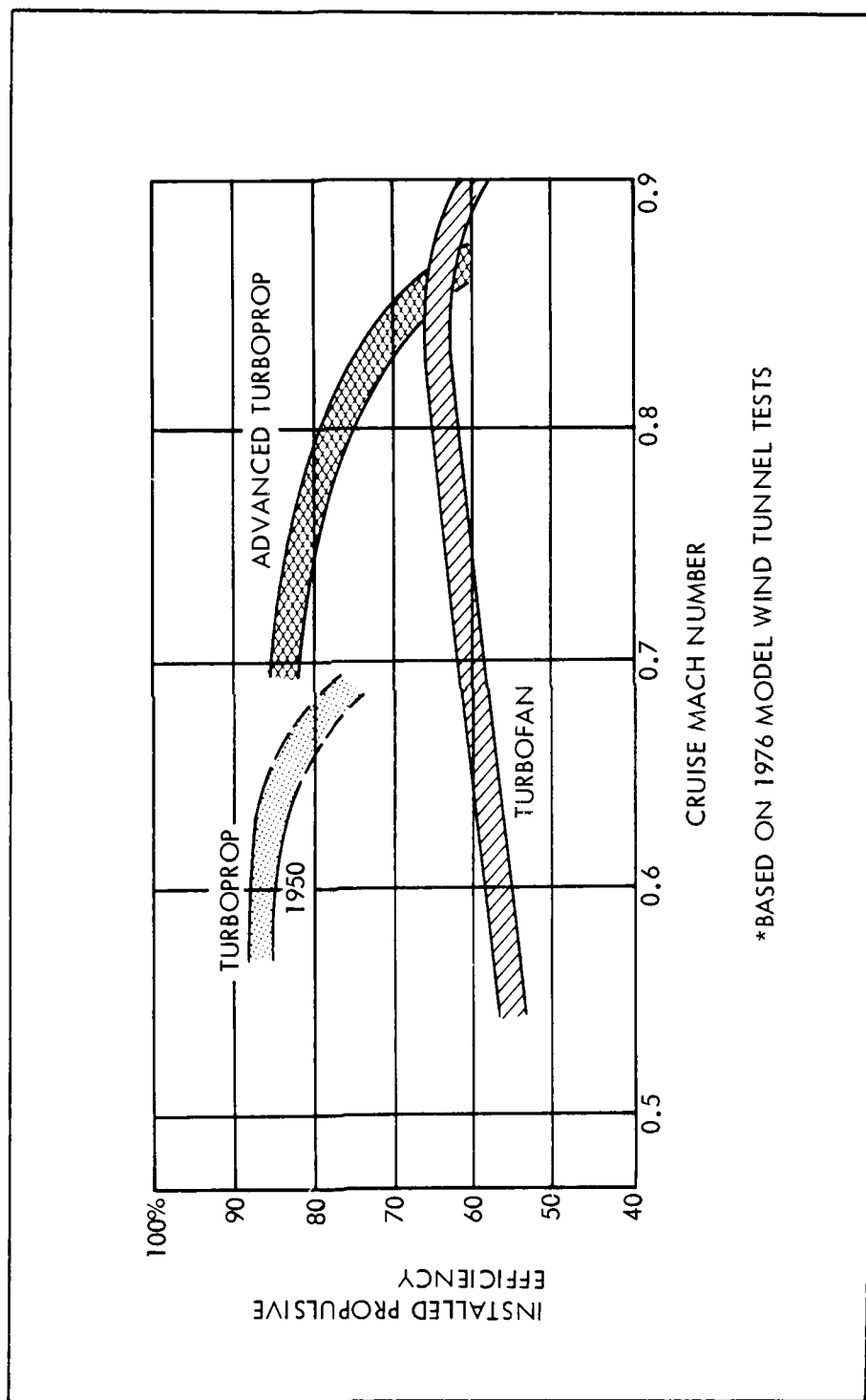


Figure 36. Propulsive Efficiencies Possible with the Prop-Fan
Source: Reference 30

apply suction to all those holes. Of major concern are the manufacturing and operating complexities of such a system. Potential fuel savings of 20 to 40 percent might be realized. To date, the risk and long development time have deterred the industry from pursuing this area; now, though, it is possible that the necessary pumping and associated hardware systems could be available by 1990 (see Reference 31).

ENERGY INTENSITY COMPARISONS

When one studies the energy issue and its implications on the future of freight transportation systems, the subject of energy intensity comparisons arises. The argument is occasionally heard that other modes are much more energy efficient than air freight. Table 4 compares some theoretical energy efficiencies expressed in terms of the energy required to move one ton a distance of one mile. This table might lead one to the conclusion that everything should be shipped by inland waterway or by rail.

TABLE 4
ENERGY INTENSITY BY TRANSPORTATION MODE

| <u>Transportation Mode</u> | <u>Theoretical BTU/Ton-mile</u> |
|--------------------------------|-------------------------------------|
| Urban truck | 1,400 - 5,000 |
| Intercity truck | 1,100 - 2,000 |
| Rail | 200 - 1,000 |
| Air | 7,000 - 14,000 |
| Water (inland) | 100 - 400 |
| Pipeline | 100 - 3,500 |

SOURCE: Reference 15

The fallacy with that reasoning is that not all modes of freight shipment are interchangeable. Since transportation is but one means of contributing toward the production of the Gross National Product, the tremendously greater speed of air transportation translates into dollars saved within the nation's economy. When these savings are greater than the incremental cost of shipment by air, air cargo is a rational choice. The demand for air transportation is likely to continue, even increase, for many years to come.

Rather than trying to compare energy efficiencies for various modes, all available technology should be used to improve the efficiency of each mode. Using new technology for airframes, engines, and flight controls, significant improvements in fuel efficiency are possible within the aviation sector.

Figure 37 compares the energy intensity of four contemporary all-cargo aircraft. The right-hand column represents the energy intensity possible for an airlifter of the 1990s. One can see that this advanced cargo aircraft could use less than half the fuel per ton-mile consumed by today's best commercial all-cargo aircraft, and the improvements are well within our technological capabilities. Fuel savings such as these are possible with a very large aircraft having a payload capacity of 390,000 pounds and a cruise speed of mach 0.78 by extensive use of composite primary structures, new turbofan technology, and supercritical aerodynamics.

Effects of Rising Fuel Costs

One might next ask how rising fuel prices are going to affect operating costs of the next generation cargo aircraft. Figure 38 clearly illustrates the fact that direct operating costs for this joint civil/military aircraft could be about 40 percent of direct operating costs for present-day cargo aircraft as fuel prices rise. The B-747-200F was chosen for this comparison because it represents the most efficient all-cargo turbofan aircraft in commercial operation today.

Critics might argue that present cargo aircraft such as the 747 could be re-engined for the 1990s. At best, with new engines, the 747 might realize a 12-percent fuel reduction, but the costs of removal and installation of the engines, redesign of mounts and pylons, and the associated effects on structures and aerodynamics would tend to offset any fuel cost reductions. Detailed cost analysis for re-engining present cargo aircraft is beyond the scope of this analysis.

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ISSUES OF COMMONALITY, VOLUME II, ISSUE ANALYSIS. (U)

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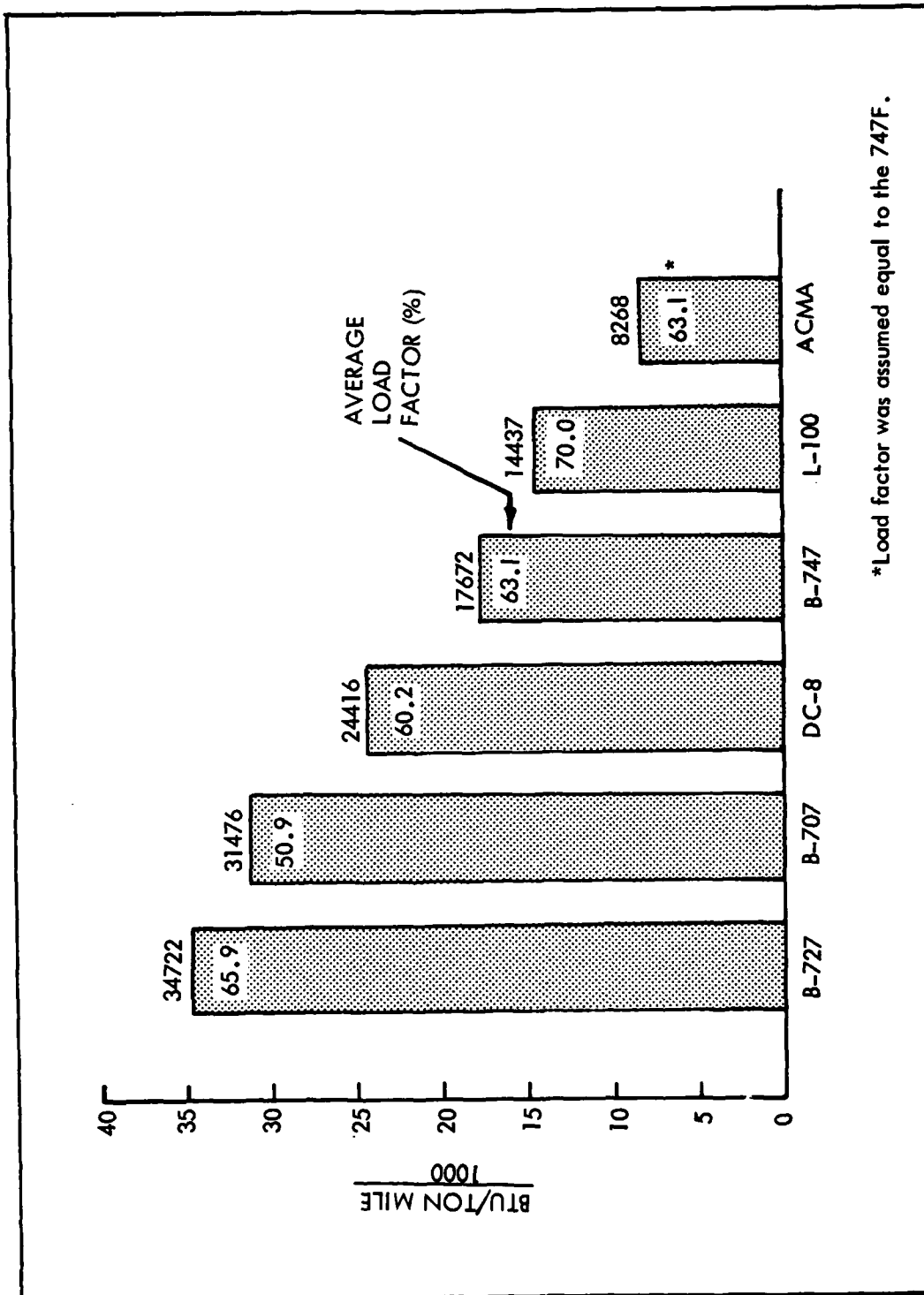


Figure 37. Energy Intensities for All-Cargo Aircraft
Source: Reference 32

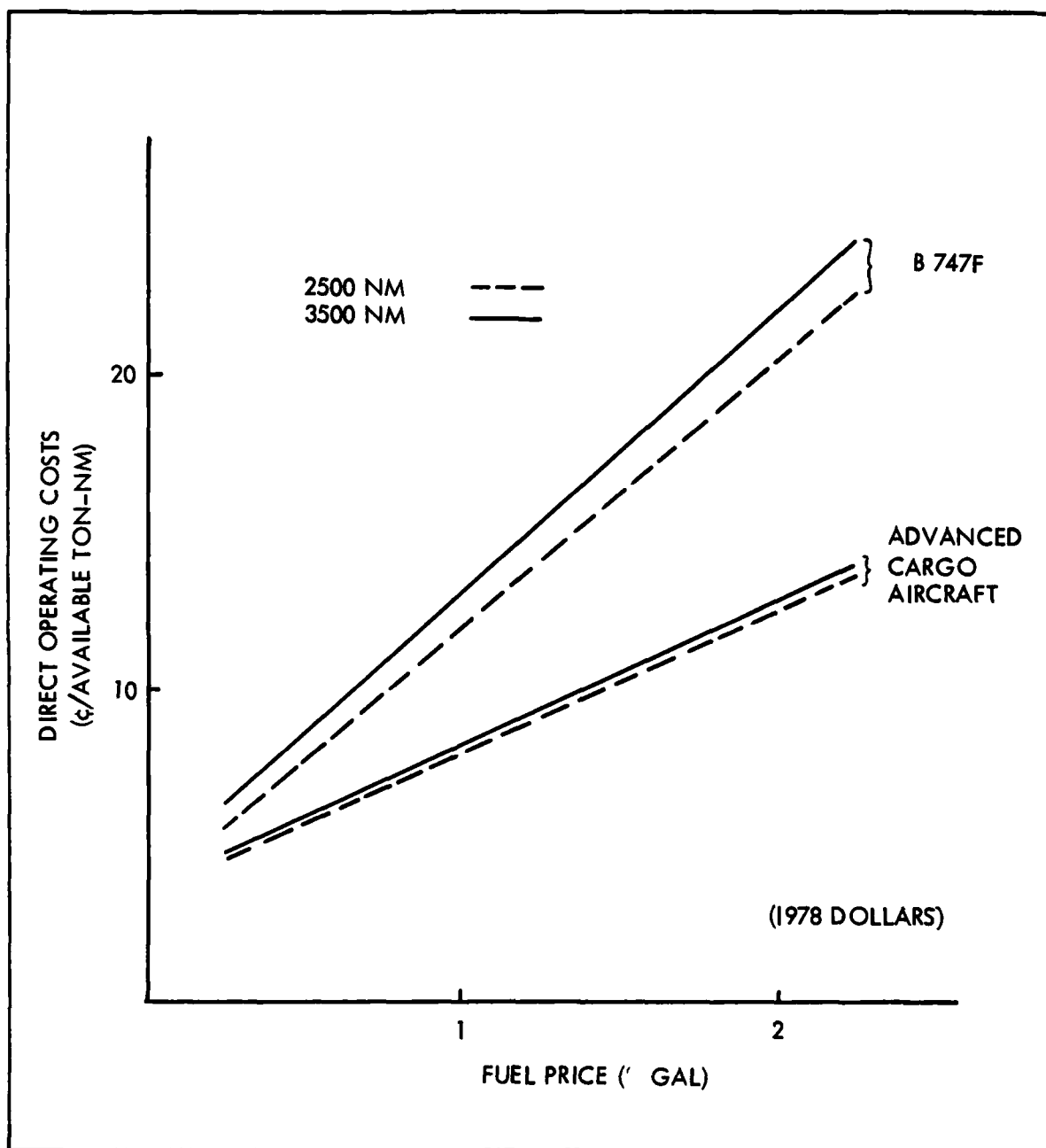


Figure 38. Effects of Rising Prices on Operating Costs

IMPACT OF A NEW AIRCRAFT ON STRATEGIC AIRLIFT

Energy considerations of a joint cargo aircraft program are especially important to the military. In addition to ever-increasing fuel prices and diminishing supplies, the United States is also losing access to valuable overseas bases. All of these factors force the military, especially the strategic airlift forces, to conserve fuel. These problems are compounded by the Air Force's high visibility to the public, thus increasing the desirability of energy-conserving strategic airlifters.

A Typical Strategic Airlift Deployment

As this report has previously mentioned, a large, highly efficient, long-range cargo aircraft is well within our capabilities. Possible fuel savings for an intercontinental mass deployment could be substantial. For example, consider the deployment of one mechanized infantry division from Fort Hood, Texas to Frankfurt, Germany. For simplicity we will assume no inflight refueling.

With our present mix of C-5A and C-141B aircraft, such a deployment will require 255 C-5A and 812 C-141B round trips (i.e., cycle sorties). Possible fuel requirements for the deployment are listed in Table 5 and possible routes are shown in Figure 39.

TABLE 5

FORT HOOD TO FRANKFURT DEPLOYMENT SUMMARY

| <u>Aircraft</u> | <u>Cycle Sorties</u> | <u>Avg. Payload (lbs)</u> | <u>Fuel Per Cycle Sortie (U.S. gals)</u> | <u>Total Fuel Required (U.S. gals)</u> |
|-----------------|----------------------|---------------------------|--|--|
| C-5 | 255 | 224,586 | 67,832 | 17,297,000 |
| C-141B | 812 | 60,223 | 36,519 | 29,653,000 |
| Totals | 1067 | | | 46,950,000 |

By comparison, the 1990s airlifter could accomplish the same deployment in 314 trips carrying an average payload of 334,735 pounds, requiring 55,340 gallons of fuel per trip. These figures yield a total of 17,377,000 gallons for the entire deployment. Compared with the C-5A/C-141B fleet, a new airlifter could save up to 63 percent. Figure 40 illustrates these comparisons.

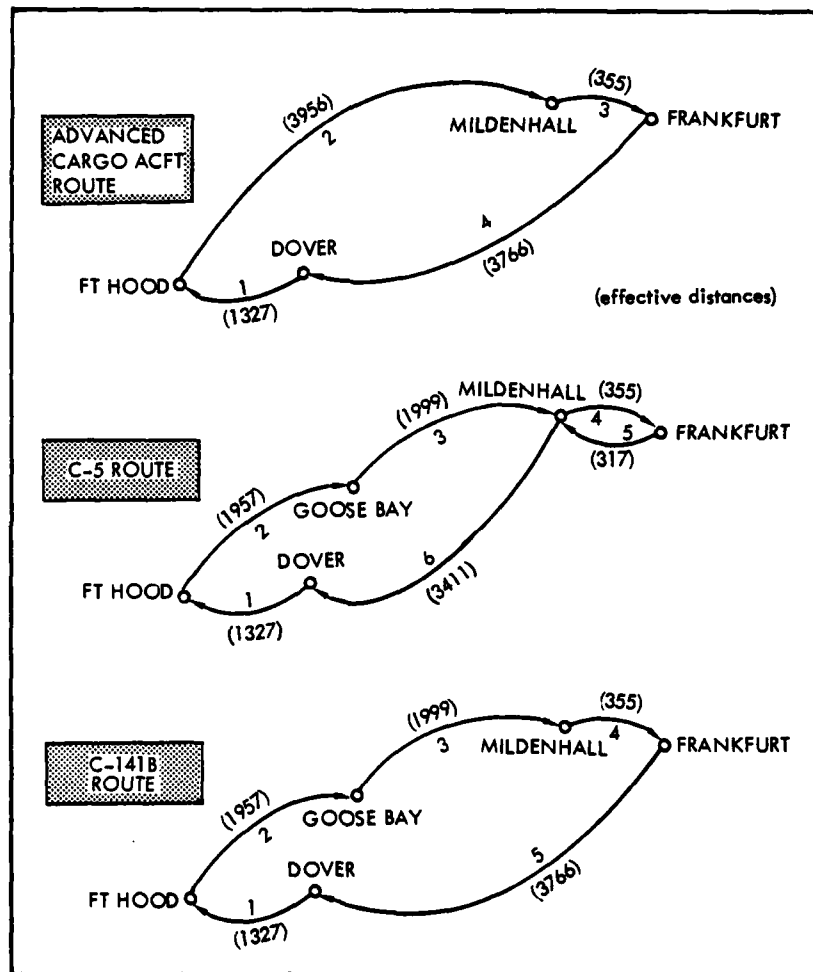


Figure 39. Deployment Routes

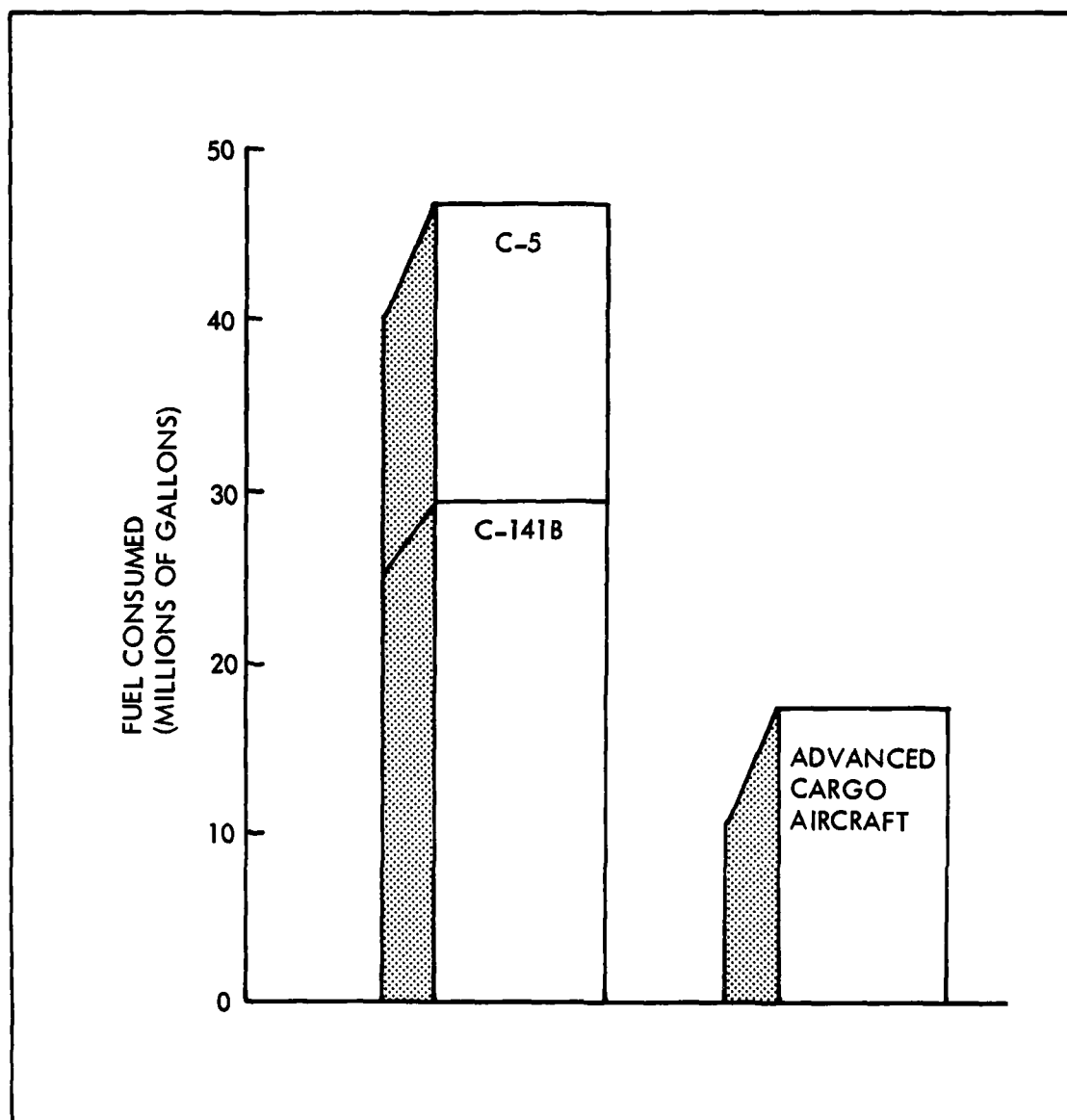


Figure 40. Comparative Fuel Requirements for a Typical European Deployment

Potential Improvements in Fuel Consumption for Strategic Airlift

The improved range, specific fuel consumption, and cargo capacity of a new airlifter would offer tremendous fuel savings in the event of another resupply effort similar to the one undertaken during the 1973 Arab/Israeli war. During that operation strategic airlift was severely hampered when overflights and forward refueling bases were denied our aircraft. Table 6 shows the magnitude of the fuel requirements from that effort. An airlift fleet of the 1990s might accomplish this mission with up to 60 percent less fuel.

TABLE 6
1973 MIDDLE EAST WAR RESUPPLY EFFORT
HISTORICAL DATA

| | Hours Flown | Fuel Flow (Gal/Hr) | Total Fuel Consumed (Gal) |
|--------|----------------|-----------------------|------------------------------|
| C-141A | 13,584 | 1,970 | 26,760,000 |
| C-5A | 4,967 | 3,380 | 16,788,000 |
| Totals | 18,551 | 5,350 | 43,548,000 |

A joint civil/military aircraft fleet could give the military the surge capability it needs without having large numbers of military airlifters sitting on the ramp during peacetime. The vast majority of these aircraft—part of the civil reserve air fleet—could belong to commercial airlines engaged daily in productive commercial activity.

V. IMPACT OF ENGINE DEVELOPMENT/ACQUISITION

Some of the technical and non-technical program considerations bearing on planning and managing the engine program for a common civil/military cargo transport planned for operational service in the mid-1990s are appraised in this section. These considerations are related to:

- o General performance requirements of representative powerplants suitable for a civil/military cargo transport.
- o Potential propulsion technology developments advantageous to the new transport.
- o Features of a representative propulsion system development program.
- o Assessment of key milestone requirements and potential impacts of the engine program on the aircraft program.

Our objective is to assess the likelihood of the engine program pacing the aircraft development program, and, if possible, to identify propulsion technology development milestones that would influence the aircraft program. To provide a context for a description of potential engines, we first discuss the level of engine performance required. This is followed by a postulated engine development program and schedule.

PERFORMANCE REQUIREMENTS

At this preconceptual stage of the ACMA program, the performance level of the engine can only be examined in terms of concurrent studies performed to examine the design options for the aircraft. (See, for example, Reference 8.) Some of these studies have suggested that large aircraft, offering considerable economies of scale, are quite attractive and would require engines with higher thrusts, improved fuel consumption, lower operating costs, and better environmental characteristics than today's engines. These considerations will be discussed in the following paragraphs.

Thrust/Shaft Horsepower

Expressed most simply, in cruise the thrust required is equal to the airplane drag. While drag is related to a specific configuration, the lift-to-drag ratio (L/D) can be used to find representative thrust levels because L/D typically falls into a predictable range for a given type aircraft. Table 7 shows required turbofan engine thrusts for three aircraft weights, for two L/Ds, and for four or six engines. For comparison, two current large transports are also shown. The weight groups shown were chosen to provide a probable upper bound for long-term engine program planning. These calculations show that engines as small as 32,000 pounds sea-level-rated thrust could be satisfactory for a six-engined, optimistic L/D, 900,000-pound cruise weight aircraft. For a 1,500,000-pound cruise weight with a conservative L/D and four engines, a rated thrust of over 100,000 pounds would be required.

Similar calculations for an advanced turboprop engine are shown in Table 8. For easy comparisons, the same weights and L/Ds were used, even though the turboprop aircraft can be expected to have more range/payload capability because of its substantially lower fuel consumption. It should be noted, however, that the propeller efficiency of 82 percent might be slightly optimistic since the Hamilton-Standard target is only 80 to 81 percent for a 35,000-foot, Mach 0.80 cruise. Rated engine horsepower are shown as ranging from about 28,000 to just under 90,000 depending on the airplane weight, L/D, and the number of engines. The propeller diameters shown were calculated using a disk loading of 37.5 horsepower per square foot of propeller disk area.

Fuel Economy

One of the factors that will determine required technology advancements for the selected engine is fuel economy. Fuel burned on a flight is a function of thrust required and specific fuel consumption (sfc). While thrust is determined from aircraft design characteristics, sfc can be improved by engine technology advancements.

TABLE 7
EVALUATION OF APPROXIMATE REQUIRED TURBOFAN ENGINE SIZE

| | | | Current Large Cargo Transport | Current Jumbo Cargo Derivative | New Civil Military/Cargo Transport | | | | | |
|---|---|------|-------------------------------|--------------------------------|------------------------------------|------------|----------|------------|---------|------------|
| | | | | | 900000 | | 35000/.8 | | 1500000 | |
| <u>AIRPLANE</u> | Initial cruise altitude Mach No. | ft/- | 28000/.75 | 30000/.78 | 17 | 23 | 18 | 24 | 18 | 25 |
| | Initial cruise weight | lb | 690000 | 775000 | 17 | 23 | 18 | 24 | 18 | 25 |
| | Airplane initial cruise L/D | - | - | Estimate | Conserv | Optimistic | Conserv | Optimistic | Conserv | Optimistic |
| | Appraisal of L/D | - | - | 43056 | 52941 | 39130 | 75000 | 56250 | 83333 | 60000 |
| | Total initial cruise drag (- thrust required) | lb | 40588 | | | | | | | |
| <u>TURBOFAN ENGINE</u> | Cruise thrust per power plant - 4 engines | lb | 10147 | 10764 | 13235 | 9783 | 18750 | 14063 | 20833 | 15000 |
| | " - 6 engines | lb | - | - | 8823 | 6522 | 12500 | 9375 | 13889 | 10000 |
| | Cruise installation loss | % | - | 14 | - | - | - | - | - | - |
| | Uninstalled cruise thrust | lb | 11531 | 12516 | 15040 | 11117 | 21067 | 15801 | 23408 | 16854 |
| | " - 4 engines | lb | - | - | 10027 | 7411 | 14045 | 10534 | 15605 | 11236 |
| | " - 6 engines | lb | - | - | - | - | - | - | - | - |
| | Cruise thrust - SL rated thrust | - | .28 | .24 | .23 | .23 | .23 | .23 | .23 | .23 |
| | Uninstalled SL rated thrust | lb | 41181 | 52150 | 65392 | 48333 | 91597 | 68698 | 101775 | 73278 |
| | " - 4 engines | lb | - | - | 43595 | 32222 | 61065 | 45799 | 67850 | 48852 |
| | " - 6 engines | lb | - | - | 261567 | 193332 | 366390 | 274792 | 407100 | 293112 |
| <u>POTENTIAL ENGINE (New or Derivative)</u> | Total uninstalled rated thrust | lb | 164725 | 208602 | 251104 | 185599 | 355398 | 266549 | 394887 | 284319 |
| | Appx. installation takeoff loss | % | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | Appx. installed takeoff thrust | lb | 158135 | 200258 | 251104 | 185599 | 355398 | 266549 | 394887 | 284319 |
| | Appx. takeoff weight | lb | 700000 | 785000 | 915000 | 915000 | 1370000 | 1370000 | 1520000 | 1520000 |
| | Appx. thrust/weight - takeoff | - | .226 | .255 | .274 | .203 | .259 | .195 | .260 | .187 |
| | Appraisal of thrust/weight | - | Acceptable | Good | Good | Acceptable | Good | Low | Good | Low |
| | | | Available | Available | Deriv | Deriv | New | Deriv | New | Deriv |

TABLE 8
ENGINE SIZE RANGE - PROPELLER POWERPLANT

| <u>AIRPLANE</u> | | | | | | | | | | |
|--|---|--------------------|---------------------|----------|-------------------|----------|----------------|----------|--|--|
| Initial cruise altitude/Mach No. | | ft/- | 35000/.8 (V=461 kn) | | | | | | | |
| Initial cruise weight | | lb | <u>900000</u> | | <u>1350000</u> | | <u>1500000</u> | | | |
| L/D | | - | 17 | 23 | 18 | 24 | 18 | 25 | | |
| Total initial thrust required | | lb | 52941 | 39130 | 75000 | 56250 | 83333 | 60000 | | |
| <u>ADVANCED PROPELLER POWERPLANT</u> | | | <u>ENG</u> | | | | | | | |
| Propeller efficiency | | - | | | 0.82 | | | | | |
| Thrust/shp(= $\eta \times .326 \div V$) | | lb/shp | | | 0.58 | | | | | |
| Installed thrust per powerplant | 4 | lb | 13235 | 9783 | 18750 | 14063 | 20833 | 15000 | | |
| " | 6 | lb | 8824 | 6522 | 12500 | 9375 | 13889 | 10000 | | |
| Installed shp per powerplant | 4 | hp | 22819 | 16867 | 32328 | 24246 | 35920 | 25862 | | |
| " | 6 | hp | 15213 | 11244 | 21552 | 16164 | 23946 | 17241 | | |
| Cruise installation loss | 4 | - | | | 200 shp + 3% aero | | | | | |
| " | 6 | - | | | 134 shp + 3% aero | | | | | |
| Cruise uninstalled shp | 4 | hp | 23710 | 17599 | 33503 | 25179 | 37203 | 26844 | | |
| " | 6 | hp | 15807 | 11720 | 22336 | 16787 | 24802 | 17897 | | |
| Cruise shp \div SL rated shp | | - | | | 0.42 | | | | | |
| SL rated shp | 4 | hp | 56453 | 41854 | 79770 | 59950 | 88579 | 63914 | | |
| " | 6 | hp | 37637 | 27904 | 53182 | 39968 | 59054 | 42611 | | |
| Takeoff installation loss | 4 | - | | | 100 shp + 2% aero | | | | | |
| " | 6 | - | | | 67 shp + 2% aero | | | | | |
| Takeoff shp installed | 4 | hp | 55225 | 40919 | 78077 | 58653 | 86709 | 62538 | | |
| " | 6 | hp | 36818 | 27280 | 52032 | 39102 | 57807 | 41693 | | |
| Cruise SHP/D ² | | hp/ft ² | | | 37.5 | | | | | |
| Propeller diameter | 4 | ft | 24.67 | 21.21 | 29.36 | 25.42 | 30.95 | 26.26 | | |
| " | 6 | ft | 20.14 | 17.32 | 23.97 | 20.76 | 25.27 | 21.44 | | |
| <u>PROPELLER POWER PLANT</u> | | | | | | | | | | |
| Takeoff SHP/D ² | 4 | hp/ft ² | 90.7 | 91.0 | 90.6 | 90.7 | 90.5 | 90.7 | | |
| " | 6 | hp/ft ² | 90.8 | 90.9 | 90.6 | 90.7 | 90.5 | 90.7 | | |
| Takeoff thrust/shp | 4 | lb/hp | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | | |
| " | 6 | lb/hp | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | | |
| Takeoff thrust/eng | 4 | lb | 69031 | 51149 | 97596 | 73316 | 108386 | 78173 | | |
| " | 6 | lb | 46023 | 34100 | 65065 | 48879 | 72259 | 52116 | | |
| Total takeoff thrust | 4 | lb | 276125 | 204595 | 390385 | 293265 | 433545 | 312690 | | |
| " | 6 | lb | 276135 | 204600 | 390390 | 293273 | 433553 | 312698 | | |
| Appx. takeoff thrust/wgt | 4 | - | .307 | .227 | .289 | .217 | .289 | .208 | | |
| " | 6 | - | .307 | .227 | .289 | .217 | .289 | .208 | | |
| Appraisal of takeoff thrust/wgt. | | - | Good | Adequate | Good | Adequate | Good | Adequate | | |
| <u>POTENTIALS</u> | | | | | | | | | | |
| Engine | 4 | | New | New | New | New | New | New | | |
| | 6 | | New | New | New | New | New | New | | |
| Propeller | 4 | | New | New | New | New | New | New | | |
| | 6 | | New | New | New | New | New | New | | |

Notes:

1. The propeller assumed is an eight-bladed propfan operating with an 800 ft/sec tip speed.
2. It might be possible to get more takeoff thrust at less than 60 kn by operating at a flat rating less than maximum thermodynamic horsepower. Resulting lower SHP/D² can result in higher T SHP and higher thrust. Also gearbox weight could be reduced since it is sized by maximum horsepower in takeoff. Detailed study is necessary to determine best takeoff procedure and performance, and the most favorable ratings.

The significance of fuel economy is illustrated in Table 9. Using today's high bypass ratio turbofan as a base, approximate variations in sfc for derivatives, the next generation engine, and advanced technology turbofans are shown. Also shown is the approximate improvement expected from the advanced turboprop engine driving the advanced technology propeller. Assuming a typical military mission of about 9.5 hours and a base sfc of about 0.67 lb/hr/lb, savings available are shown to range from about 4 percent to 16 percent for a turbofan powered aircraft, and up to about 32 percent for the turboprop. At \$1.00 per gallon fuel, and 100 missions per year, savings in mission operations would be about \$760,000 annually per turbofan airplane at the 16 percent savings level. For the turboprop, savings from the base fuel consumption jump to about \$1.5 million per airplane each year. This level of savings could be used to offset the probable higher development costs associated with the advanced turboprop. In fact, if the total development cost of the propfan powerplant were \$250,000,000 more than the turbofan, the difference could be made up by only 11 aircraft operating for their 30-year lifetime at the fuel savings cited previously. For the civil operator at his higher utilization rates, the fuel savings for the propfan are even more impressive. The many development problems facing the propfan will be discussed subsequently in this issue report.

Environmental Considerations

Certainly, for the civil version, and most likely even for the military version of the ACMA, limitations on noise and engine emissions will impact aircraft and engine design. For example, civil aircraft of new type designs are currently required to demonstrate compliance with FAR Part 36, Stage 3 requirements. The Stage 3 noise limits for a four-engined airplane and noise measuring locations are shown in Figures 41 and 42. Some, but not all, models of current wide-bodied transports can comply with these requirements. The Environmental Protection Agency (EPA) proposal for a post-1985 aircraft which was published in the 28 October 1976 Federal Register, would further lower these limits for future commercial airplanes. These proposals are widely considered throughout the industry as technically impractical and economically unreasonable. However, the basic Stage 3 limits should be reviewed periodically to determine the appropriateness of further noise level reductions.

TABLE 9

THE FUEL ECONOMY PICTURE

Comparative sfc's and typical fuel savings

| <u>ENGINE</u> | | | <u>TSFC</u> |
|---------------|---|---------------------|-------------|
| • | CF6 | JT9D RB211 families | Base |
| • | Derivative of above | | |
| | Type 1: thrust increased by TIT increase | | +0.5 to 3% |
| | Type 2: cycle and hardware improvements, near term | | -3 to 5% |
| | Type 3: further cycle and hardware improvements, late - 80's | | -8 to 10% |
| • | Next generation turbofan: E ³ high bypass ratio | | -12% |
| • | Advanced technology turbofan: 1995-2000 | | -16% |
| • | Propfan and advanced technology power section: 1995-2000 | | -32% |

MISSION FUEL SAVINGS

- Typical 9.5 hours cruise (at 461 kn gives 4380 nm cruise. With climb and descent added, range would be near 4500 nm)
- Say cruise drag (thrust) averages 50,000 lb, and installed sfc of typical current engine (base) is about 0.67. Base cruise fuel consumed is 318,250 lb per mission
- Savings - derivative Type 2 4% 12,730 lb per mission
 - derivative Type 3 8% 25,460 "
 - E³ 12% 38,190 "
 - advanced turbofan 16% 50,920 "
 - propfan 32% 101,840 "
- The calculated values would increase slightly because of comparable improvements in non-cruise mission segments, and because of the compounding effects of lower fuel weight and reduced gross weight. Likewise, some of the improvement could be offset by engine installation losses greater than accounted for in these calculations, and in powerplant/aircraft interference effects not considered.

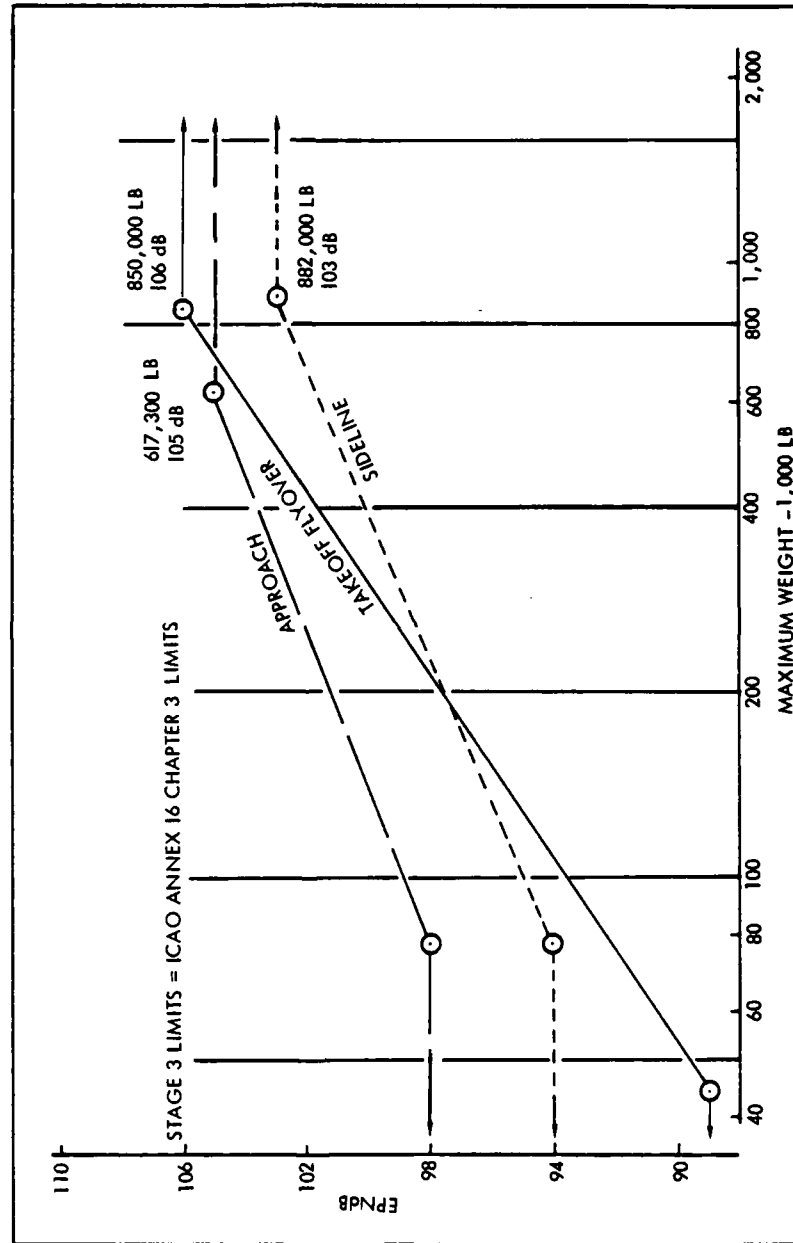


Figure 41. FAR 36 Stage 3 Noise Limits

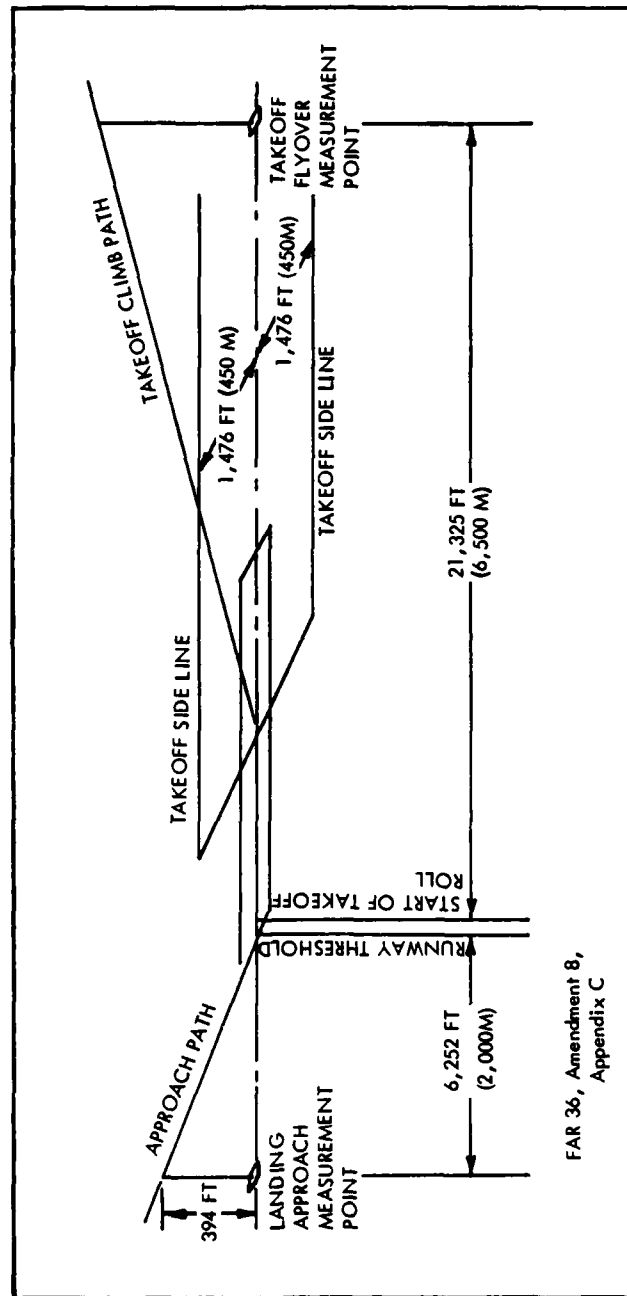


Figure 42. FAR 36 Noise Measuring Points

Current projections suggest a possible reduction in these standards by about 2 EPNdB at each location for new airplanes in the mid-1990s which incorporate advanced technologies. Compliance with these noise requirements in an economic manner, especially at higher airplane weights, requires careful selection of engine cycle parameters, proper nacelle acoustic design, and good airfield performance. Design for compliance is thus an integral part of the entire airplane design process.

Existing military transport aircraft do not have noise compliance requirements. However, Air Force Regulation 80-36 states that all future transport aircraft procured by the Air Force must be designed to comply with civil airworthiness standards, including FAR Part 36, when their intended use is generally consistent with civil operations, providing that compliance does not impose unacceptable performance degradation, high costs, etc. Thus the cost of FAR Part 36 compliance needs to be included for military as well as civil applications.

The EPA has established quantitative limits for gaseous emissions of carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NO_x), and smoke from aircraft engines of the types and sizes likely to be used by the civil/military cargo transport. After January 1984, two separate sets of rules will be applied to new aircraft. One set will be for newly manufactured engines and the other for newly certified engines. The emission standards for the latter are somewhat more stringent than for the former.

Technologies for reducing engine emissions have been under investigation for a number of years by the engine manufacturers using both NASA and in-house funding. Emissions reductions in current production engines have been significant and offer promise for future reductions to meet the more stringent standards. Smoke, for example, has already been virtually eliminated in today's engines. Most recent studies indicate that known advanced combustor technology can result in the required reductions in newly manufactured engines starting in 1984. However, the engine manufacturers indicate that there are significant engine operational and economic problems still to be overcome. For newly certificated engines the proposed 1984 standards are more stringent, and engine manufacturers are doubtful that expected technology advancements will result in engine operation at the reduced emissions levels.

we anticipate that future changes to emissions limits will reflect the ability of further technology advancements to satisfy them, and that whatever standards apply to the mid-1990s aircraft will not preclude development of technology for engines and aircraft superior in the use of energy, manpower and material resources. Thus, mandated emissions limitations by themselves should cause no program schedule delay in development of the new common cargo transport.

COSTS OF OWNERSHIP

The cost to own an engine is made up of its acquisition cost (with development amortized), the cost of the fuel it consumes, and the cost to maintain it. Maintenance includes periodic/scheduled preventive maintenance, repair of minor part failures, replacement and repair of modules, and overhaul of modules or the entire engine (and propeller for a turboprop installation). The objective of the operator is to minimize the total cost of ownership; therefore, the various elements can be traded off against one another.

It is desirable to hold acquisition cost to a reasonable minimum to keep initial investment and capital requirements down. For this purpose, derivatives of existing engines are most promising. Advanced technology for fuel conservation and better specific performance will add to the initial cost of a new type engine. Current experience indicates that regulatory limitations and qualification/certification will be more difficult and will also tend to increase new engine prices. In all, the acquisition cost of a new, advanced technology engine (with development amortized) will be substantially more per pound of thrust developed than the acquisition cost of a derivative engine.

A detailed study of specific engines and aircraft is necessary to obtain specific estimates of savings from lower sfc. The very brief evaluation in the previous subsection strongly suggests, however, that what seems to be a small improvement in fuel economy will amount to very large savings over the operating life of the engine. That and similar experience from past studies indicate that fuel savings resulting from E³ technology in the 1990s advanced technology engine or the advanced technology turboprop will quickly pay off in the design of a new engine and its application to a new airplane.

Improved reliability will probably pay off if it is obtained by a reduction in the number of parts or simplification of design. It may or may not pay if it is obtained by use of higher cost, high-reliability components in a complex design. This is especially true in the high-utilization civil operation where loss of revenue as a result of airplane downtime can reach significant levels very quickly. In lower utilization peacetime military operations, longer ground times can accommodate resolution of many malfunctions and failures, although readiness can be unfavorably impacted. During a military emergency or wartime deployment, however, downtime can severely impact airlift productivity. It is clear that improved reliability is very desirable in both civil and military operations.

Reduced maintenance manhours and material costs per engine hour are always advantageous but not equally easy to obtain. For the basically mature derivative engines, operating experience, spare parts inventory efficiency, and a well developed support network will help keep costs lower. For the advanced technology new engine, more costly parts, engine immaturity, and the necessity to establish the support network add to its cost. A design objective should be to measurably improve the new engine failure rate and the shop visit rate.

POTENTIAL ENGINE CANDIDATES

Just what engines will be available for the 1995 civil/military transport is by no means certain. It can be expected that some derivatives of today's large high-bypass-ratio transport engines will be in production. It is also reasonable to expect that the next generation engine, most likely represented by something like E^3 technology or a derivative of it, will be in production. Engines representing further technology advancements are not likely to be available unless development is started in the mid-1980s to support the 1995 IOC aircraft. The transport engine picture as of the third quarter 1979 is shown in Table 10. This table lists transport engines in production, committed derivatives, and a new engine, the CFM56, which was certified in November 1979. Also listed are applicable technology development programs, various engineering studies, some advanced technology engine studies, and other general technology studies. None of the production, development, or study

TABLE 10
THE TRANSPORT ENGINE PICTURE: 1980-2000

1. Manufacturer activities - as of third quarter 1979
2. Sponsored programs/studies - commercial, NASA, military
3. Larger engines, large aircraft - in order of 20,000 lb. thrust and more

CURRENT TURBOFAN PROGRAMS

| Company | Family | Thrust Range | Initial Certification/Qualification | Application |
|---------|---------------------------|--------------|-------------------------------------|--------------------------|
| GE | TF39 ⁽¹⁾ | 41000 | 1968 | C-5A |
| GE | CF6-6 | 40-41500 | 1971 | DC-10 |
| GE | CF6-50 | 51-54000 | 1972 | DC-10, B747, A300 |
| GE | CF6-80 | 44-54000 | 1982 | DC-10, B747, A300, A310 |
| GE | CF6-32 ⁽²⁾ | 30-39000 | 1981 | B757 |
| GE | CF6-45 ⁽³⁾ | 44-48000 | 1981 | B747 |
| P&W | JT3D/TF33 ⁽⁴⁾ | 17-21000 | 1964 | DC-8, B707, C-135, C-141 |
| P&W | JT8D-1 to -17 | 14-17400 | 1963 | DC-9, B727, B737, Others |
| P&W | JT8D-200 Series | 18-21000 | 1979 | DC-9 |
| P&W | JT9D-1, -3 ⁽¹⁾ | 44000 | 1-70 | B747 |
| P&W | JT9D-7, 20 | 47-53000 | 72 | B747, DC-10 |
| P&W | JT9D-59, 70 | 53-54500 | 1975 | DC-10, B747, A300 |
| P&W | JT9D-78, 4 | 44-56000 | 1980 | DC-10, A300, B767 |
| RR | RB211-22 | 42000 | 1972 | L-1011 |
| RR | RB211-524 | 50-53000 | 1975 | L-1011, B747 |
| RR | RB211-535 ⁽²⁾ | 32000 | 1982 | B757 |

NEW TURBOFAN IN DEVELOPMENT

| | | | | |
|--------------------|-------|----------|------|----------------|
| CFM ⁽⁵⁾ | CFM56 | 22-24000 | 1979 | DC-8 re-engine |
|--------------------|-------|----------|------|----------------|

TECHNOLOGY DEVELOPMENT

| Company | Sponsor | Program |
|---------|---------|--|
| GE | NASA | Energy Efficient Engine (E ³) - demonstrator |
| P&W | NASA | |
| Ham Std | NASA | Advanced Technology Propeller (Propfen) |

MARKETING AND ENGINEERING STUDIES

| Company | Sponsor | Program |
|---------|-------------------------|---|
| GE | In-house | Further CF6 derivatives |
| GE | In-house | CFM56 derivatives |
| GE | In-house | E ³ derivatives |
| P&W | In-house | Further JT8D derivatives |
| P&W | In-house | Further JT9D derivatives |
| P&W | In-house | JT100 high bypass ratio turbofan family |
| P&W | In-house | E ³ derivatives |
| RR | In-house ⁽⁶⁾ | Further RB211 derivatives |
| RR | In-house ⁽⁶⁾ | RB432 high bypass ratio turbofan |

ADVANCED TECHNOLOGY ENGINE STUDIES

| Company | Sponsor | Designation/Type | Study Date | Certification | Unit Thrust (lbs) | Sea level (lbs) |
|---------|----------|---------------------|------------|-----------------------------|-------------------|-----------------|
| DDA | In-house | PD370-22, Turboprop | 1976 | 1985 ⁽⁷⁾ | - | 12328 |
| P&W | NASA | STF477 Turboprop | 1974-75 | 1998 ⁽⁷⁾ | 26550 | - |
| P&W | NASA | STF487 Turboprop | 1974-75 | 1998 | - | 20424 |
| P&W | In-house | STF482 Turboprop | 1975 | Early - 20's ⁽⁸⁾ | 60000 | - |
| P&W | In-house | STF530 Turboprop | 1978 | Mid-late 80's | 22471 | - |
| P&W | In-house | STP541 Turboprop | 1978 | Mid-late 80's | - | 18600 |

COMPLETED STUDIES, PROPOSED STUDIES

| Company | Sponsor | Study | Date | |
|-------------------------|---------|-------|------|------------------------------------|
| GE | Navy | MAACE | 1979 | - Multiple Application Core Engine |
| P&W | Navy | MAACE | 1979 | - |
| Proposed ⁽⁹⁾ | Navy | LRPP | 1980 | - Long Range Propulsion Plan |

AREAS WITH NO EVIDENT CURRENT ACTIVITY

- a. Large turboprop/turboprop - in horsepower range noted in Table III
b. High horsepower gas-turbine - in horsepower range noted in Table III
c. Very large turbofan - Above 70,000 lb thrust

POTENTIALLY RELATED TECHNOLOGY DEVELOPMENT

- a. ATEGG - USAF programs oriented primarily to component advancements, primarily initially
b. APSI - applicable to high performance aircraft

Footnotes

1. Out of production
2. Reduced fan diameter derivative
3. Revised per modified CF6-50
4. TF33-PA-100 in production for E-3A
5. Joint company of General Electric and SNECMA
6. Government owned company
7. Revised by P&W to later date than stated in study
8. As stated in study. Would probably be stopped if program were activated
9. DDA, GE, P&W, A/R Research, AVCO Lycoming, Teledyne CAE, possibly Williams Research could all participate

engines are in the 100,000-pound thrust range required by the larger potential transports. In addition, no development or comprehensive engine studies are being conducted for the smaller, 20,000 shp class, turboprop engine which might power a smaller propfan aircraft.

In the following subsections we review some of the considerations that will lead to selection of an engine for the AQMA, with emphasis on technology development programs that are required.

Derivative Engines

Growth versions of the JT9D, CF6, and RB211 turbofans will be in production into the late 1980s. Thrusts are not likely to substantially exceed 65,000-70,000 pounds and sfc is likely to be perhaps 4 percent better than the early-80s derivatives presently planned. Table 7 shows that 65-70,000 pounds thrust will be suitable for six-engined civil/military transports up to 1,500,000 pounds or more weight. That thrust range would also be suitable for four-engined aircraft up to a weight of about 1,000,000 pounds. It appears that larger growth versions of the JT9D, CF6, or RB211 could be used on that size new aircraft.

Potential advantages of the derivative turbofan are:

- o Lower acquisition cost, less new investment money, less interest cost
- o Shorter development time
- o Basic engine maturity and superior reliability early in the program

Potential disadvantages are:

- o Higher life-cycle cost because of higher fuel consumption
- o Little growth for larger derivatives of the aircraft
- o Lower thrust-to-weight ratio

New Development Engines

The only new transport engine currently being developed is the GE/SNECMA CFM56. At its thrust of 24,000 pounds, with expected growth to about 28,000 pounds, it is too small for any expected large cargo transport. The Pratt & Whitney JT10D is a somewhat newer and more advanced engine than the CFM56. Demonstrator versions have been built and run at about 26,000 pounds thrust but the engine is not yet committed to production. Current marketing of the JT10D family includes versions of up to about 40,000 pounds thrust. The technology of the JT10D is almost that to be incorporated into the E³ engine which will be discussed in the next section. It is believed that a slight improvement over the technology level of E³ can be obtained for JT10D derivatives in time for early ACMA flight tests with few schedule or technical performance risks if the desired engine size is identified by 1984 and hardware development is under way by 1987.

New Advanced Technology Turbofans

Two levels of turbofan technology advancement between now and the year 2000 have been identified and are listed in Table 10.

- o Energy Efficient Engine (E³) - 12 to 15 percent sfc improvement in the installed powerplant
- o 1998 Certification Engine - additional 4 to 5 percent sfc improvement over the E³

The E³ program, started in 1978, is being supported by NASA with funding to both General Electric and Pratt & Whitney for engine component improvement. Core engine demonstrators are to be run in 1982, and integrated core/low spool demonstrators are to be run in 1983. Current E³ targets are for a 12 percent cruise sfc reduction and a 5 percent DOC reduction compared to today's engines. Both GE and P&W are estimating that these targets will be exceeded with their engines, which are sized in the 40,000-pound thrust class. The NASA program is not intended to result in a marketable engine, but both companies are absorbing a substantial portion of the program cost and expect to apply

the E³ technology to engines introduced in the mid-1980s and beyond. Compared to derivative engines, development investment and its effect on the acquisition cost of an E³ engine will be substantially greater; but, fuel savings and lower DOC can be expected to more than equal the greater development and initial costs over the life of the aircraft.

Pratt & Whitney identified STF477 turbofan and STS487 turboshaft engines in 1974-1975 NASA studies that incorporated technology that was, as it turns out, advanced beyond that of E³. They have identified the certification date as 1998, and have provided the data shown in Figures 43 and 44 to adjust sfc and weight for engines with earlier technology and certification dates. Note that E³ technology is shown by Pratt & Whitney with a 1988 certification. No detailed design work has actually started on the STF477 or STS487; therefore, program considerations of these engines would reflect the whole gamut of technology advancement, configuration definition, sizing, and development. While the improved sfc of about 16 percent compared to current engines, and about 4 percent compared to E³, favors development, the currently predicted certification date is not compatible with the desired mid-90s service date of the ACMA. The 1998 date could be moved forward a few years if technology work were started right away, but this is unlikely because of E³ activities. We conclude, therefore, that a technology level better than E³, but not quite as good as the STF477, is attainable and should be pursued for the early 1990s first flight tests of the new common transport.

Advanced Technology Turboprops

Manufacturers of large turbine engines apparently view turboprop technology as an outgrowth of turbofan advancements, which is to be expected since their primary business is in turbofans. Even Detroit Diesel Allison, which is the most active U.S. producer of "large" turboprop engines has not published preliminary design study results for advanced turboprops larger than about 12,000 shp (scalable to about 18,000 shp). As shown in Table 10, the only activities related to new turboprops are associated with technology levels derived from turbofans and are based on a common core application. The manufacturers have suggested that modified or possibly even new test facilities would be required for turboprop engines of the sizes in Table 8, with

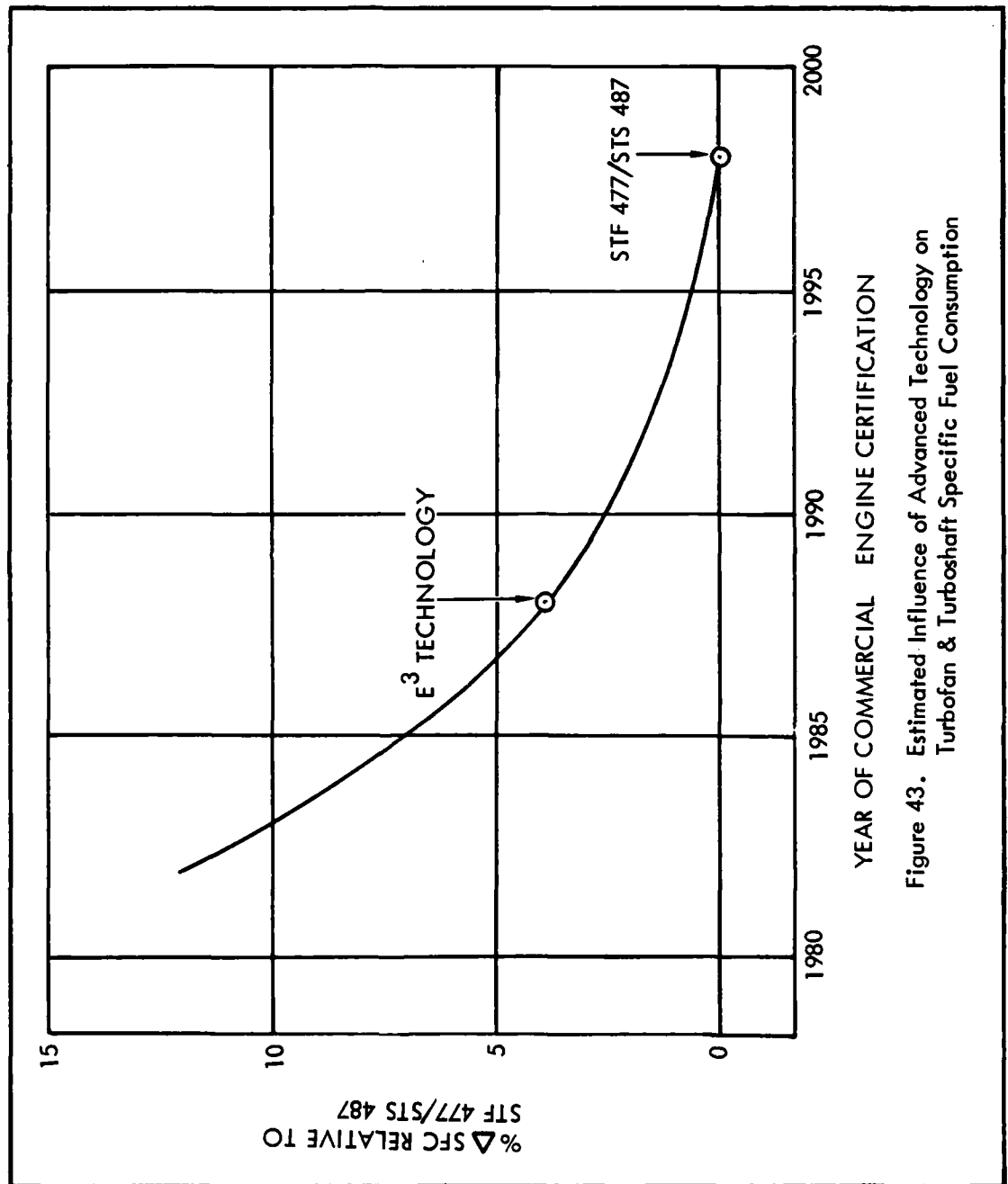


Figure 43. Estimated Influence of Advanced Technology on Turbofan & Turboshaft Specific Fuel Consumption

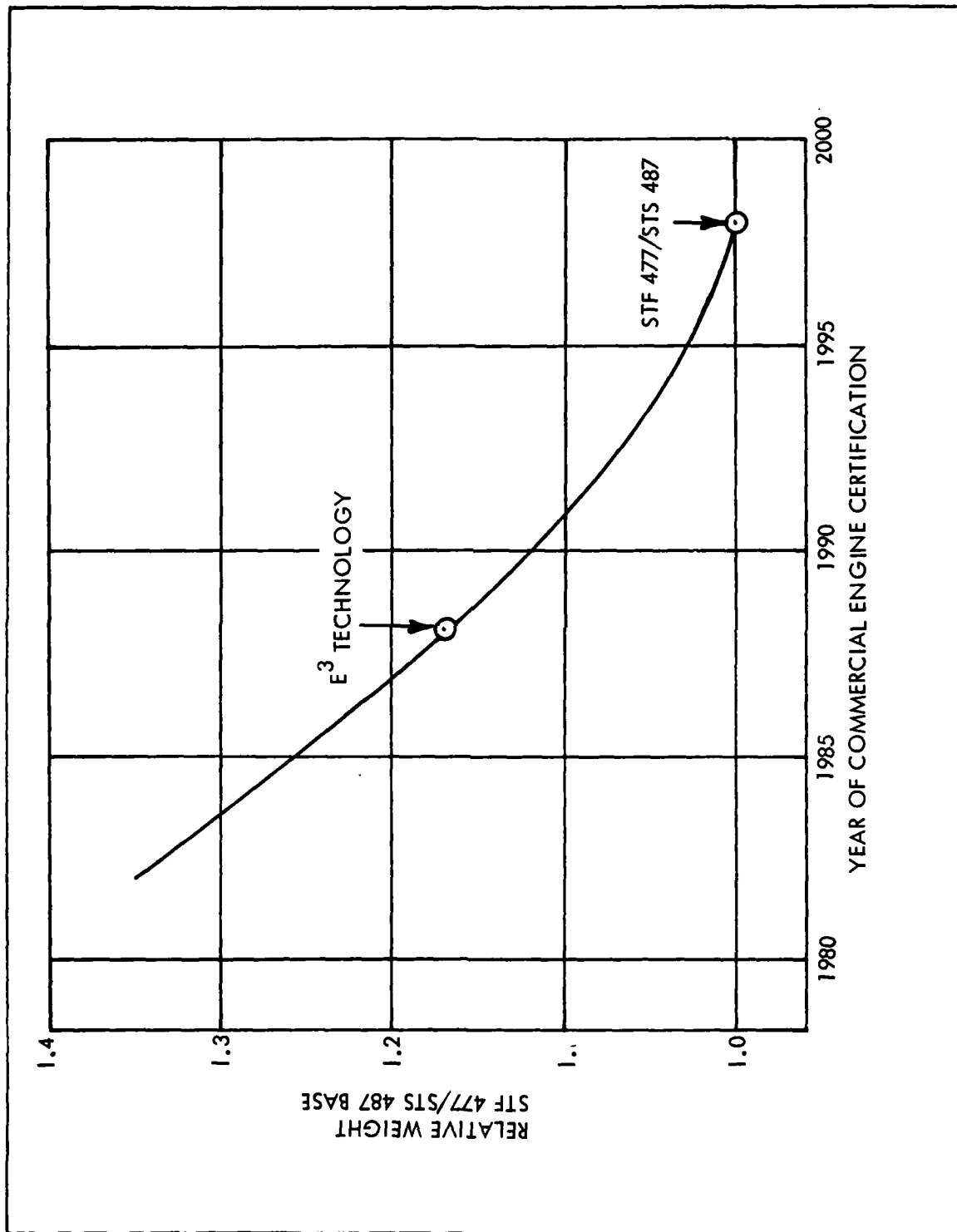


Figure 44. Estimated Influence of Advanced Technology on Turbofan & Turboshaft Engine Weight (Thrust/ Shaft Horsepower = K)

special problems in power absorption methods. However, General Electric, Pratt & Whitney, Detroit Diesel Allison, and Rolls Royce have all derived shaft-output stationary powerplants from aircraft engines. The largest of these is in the 50,000 shp class. Also, substantially larger industrial turbine power plants have been produced to drive electric utility generators, so we believe that accurately measuring power output should not be an unusually difficult problem.

There are a number of technical and non-technical factors unique to the large turboprop that bear on its application/selection for the common cargo transport. For instance, the propeller diameters shown on Table 8 range from 17 to 31 feet. While propeller component development can probably be supported in existing facilities with little or no change, there are no active facilities and no plans for construction have been noted to accommodate complete turboprop engine assemblies of this size. This is a key consideration because it would require time for planning, design, and construction or modification. By using existing stationary gas turbine powerplants and new outdoor test stands, however, this capability could probably be acquired at a reasonable cost and with no significant risk to 1995 IOC aircraft program schedules.

The results of the NASA Turboprop Cargo Aircraft Systems Study (Reference 34) indicate that disk loadings lower than those used in this report, and thus, even larger propeller diameters, may be necessary to reduce noise to acceptable levels. Another technical problem not yet being addressed is the speed reduction gearbox which is an integral component of the turboprop engine assembly.

Expanded airline and military acceptance of the return of propeller driven aircraft will aid in further development of the propfan. The fuel economy potential of the propeller powerplant might be adequately convincing, especially if proved by a demonstrator. Current cost of ownership, that is, relatively low reliability and high maintenance requirements must be improved to add a persuasive base for selecting the advanced technology propeller. Demonstrations should also be made of the ability to attenuate propeller noise with reasonable techniques and weights.

It is unlikely that the technology base for the large, advanced technology propeller will be developed without continuing the support already initiated by NASA. Additional specific program support will be required for the propeller to be used on the 1995 transport. Even with the improved fuel economy potential of the turboprop powerplant, it presently does not seem likely that industry will take the initiative to develop turboprops in the size category necessary for the 1995 common civil/military cargo transport.

TIMING OF THE ENGINE PROGRAM

In the United States, large transport aircraft and their primary propulsion engines are produced by wholly separate manufacturers. New airplane designs and existing engines, or their derivatives, have been adapted to each other and new airplanes and new engines have been developed concurrently and tailored to each other. Successful programs of both types have been completed in both civil and military transports since the turbine engine was introduced in the 1950s; however, there has not been a dedicated cargo transport developed exclusively for civil applications.

Both the Lockheed C-5A and the Boeing 747 were new transports powered by concurrently developed, new, high-bypass-ratio turbofan engines. Earlier, the C-141A was developed with a low-bypass-ratio derivative turbofan; and, while this basically military cargo transport was also certified by the FAA for civil application, none were procured by commercial operators. The Boeing 767 and 757 passenger transports now in development are to be powered by derivative, high-bypass-ratio turbofans. And, certain versions of the now venerable Douglas DC-8 are to be re-engined with a new high-bypass-ratio turbofan, the CFM56, which is based on a core engine originally intended for a supersonic bomber. The most recent "large" U.S. turboprop cargo transport is the C-130 which was developed in the mid-1950s. Its propulsion technology however, is not representative of that to be considered in this assessment of faster, higher flying, much larger aircraft.

Engine Procurement Systems

The engine procurement process used by civil operators is significantly different from that used by the military. For commercial aircraft, engines are

typically selected by the eventual operator from alternatives provided by the aircraft manufacturer and sold with the airplane; although, on occasion the operator has purchased them prior to aircraft delivery. The commercial operator usually negotiates engine guarantees and service warranties directly with the engine manufacturer. For military operations, engines have typically been selected by the service operator and the engine program funded and managed separately from the aircraft. The military service maintains in-depth observation of the development program, then usually assumes the risk of engine reliability and pays for improvements through a funded engine component improvement program (CIP) conducted by the manufacturer.

Some of the differences between commercial and military procurement in the basic decision-making process are listed in Table 11. Fundamentally, the commercial operator is governed by the necessity to make a profit and show a reasonable return on investment. The military must maintain the ability to provide an airlift capacity, in terms of both the size of equipment and the total tonnage to be moved in a prescribed time period. The goal is to satisfy both requirements with affordable investment, operating cost, and life cycle cost.

Program Timing

The representative schedule for development of a new aircraft shown in Figure 12, in Section III, and derived as a part of the analysis of the financial planning issue, reflects a typical civil/military development program that could occur based on the various government procurement directives.

A representative engine development schedule for a new military engine is shown in Figure 45. This schedule is based primarily on experience with the TF39 engine for the C-5A, but it reflects published schedules for other military engine programs. It assumes that the new engine would be tailored to a specific aircraft. It does not necessarily consider the impact of specific government procurement regulations, but does show that a reasonable program can evolve. It also reflects competitive development up to "Production Award." The pre-go-ahead years are devoted primarily to studies defining engine requirements in addition to developing the technology necessary to support the final design.

TABLE 11

COMMERCIAL AND MILITARY PROCUREMENT DECISION DIFFERENCES

| <u>Commercial</u> | <u>Military</u> |
|--|---|
| <p>Business Decisions</p> <ul style="list-style-type: none"> • Life remaining in existing fleet • Traffic projections • Intended expansions • DOC, Profit, ROI • Competition pressures | <p>Strategic Decisions</p> <ul style="list-style-type: none"> • Peacetime troop commitments • Wartime airlift readiness • Capacity of existing fleet • Life remaining and attrition of fleet |
| <p>Political/Regulatory Impacts</p> <ul style="list-style-type: none"> • Capacity/frequency limiting • Route approvals • Energy allocation • Operational regulation (such as noise and emission standards) • Image/Public Relations | <p>Budgetary Decisions</p> <ul style="list-style-type: none"> • Climate for military spending • Trade off with other military programs • Trade off with other government programs <p>Operational Use</p> <ul style="list-style-type: none"> • Training • Reserve, National Guard • Joint civil/CRAF |
| <p><u>Mutual Interests</u></p> <ul style="list-style-type: none"> • Lower life-cycle cost • Better adapted to mission • Reduced investment • Up-front money required • Wider amortization | |

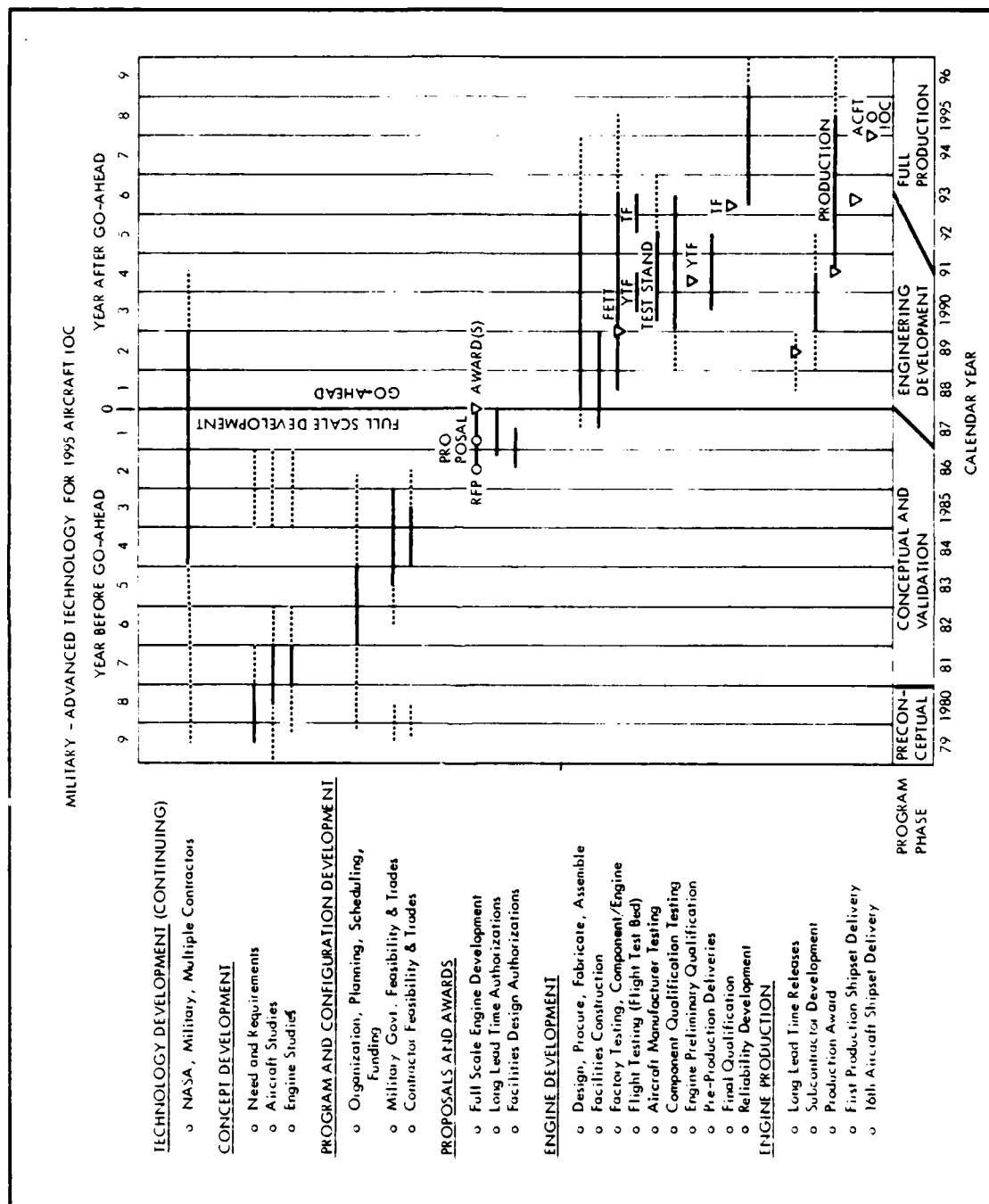


Figure 45. Representative Transport Engine Development (Military)

A similar development schedule for a new commercial transport engine is shown in Figure 46. The zero time base of this schedule corresponds to a time somewhat later than the zero time of the military development schedule. The commercial "First Firm Order" date corresponds most nearly to the military "Production Award." It takes about four and one-half to five years to go from the commercial order date to certification and the concurrent first production engine delivery. At the time of the first firm order, considerable demonstrator-engine running time will probably have been accumulated. In the military program, the time from first engine run to qualification can be expected to take about three years or so, with about two years from full-scale development go-ahead until the first engine run.

Neither of these schedules reflects an expedited program, and both are very susceptible to decision making, funding uncertainties, and other market/management/political influences. Also, neither of the two schedules reflect the possible need for new development facilities (especially for altitude test capability), or new manufacturing capability (especially for large castings and forgings), and for machining large diameter parts.

The development/certification schedule for a typical derivative engine program is shown in Figure 47. In this program, growth, improved technology, and improved reliability are incorporated into the derivative engine. Once the potential market is defined and the go-ahead decision is made, the development proceeds as a typical engine certification program. The testing for proof-of-design with early configurations is greatly reduced, however, so the program is shortened basically to that necessary for validation of the changes and certification. Even so, more than four years can be required from the commitment to proceed until certification.

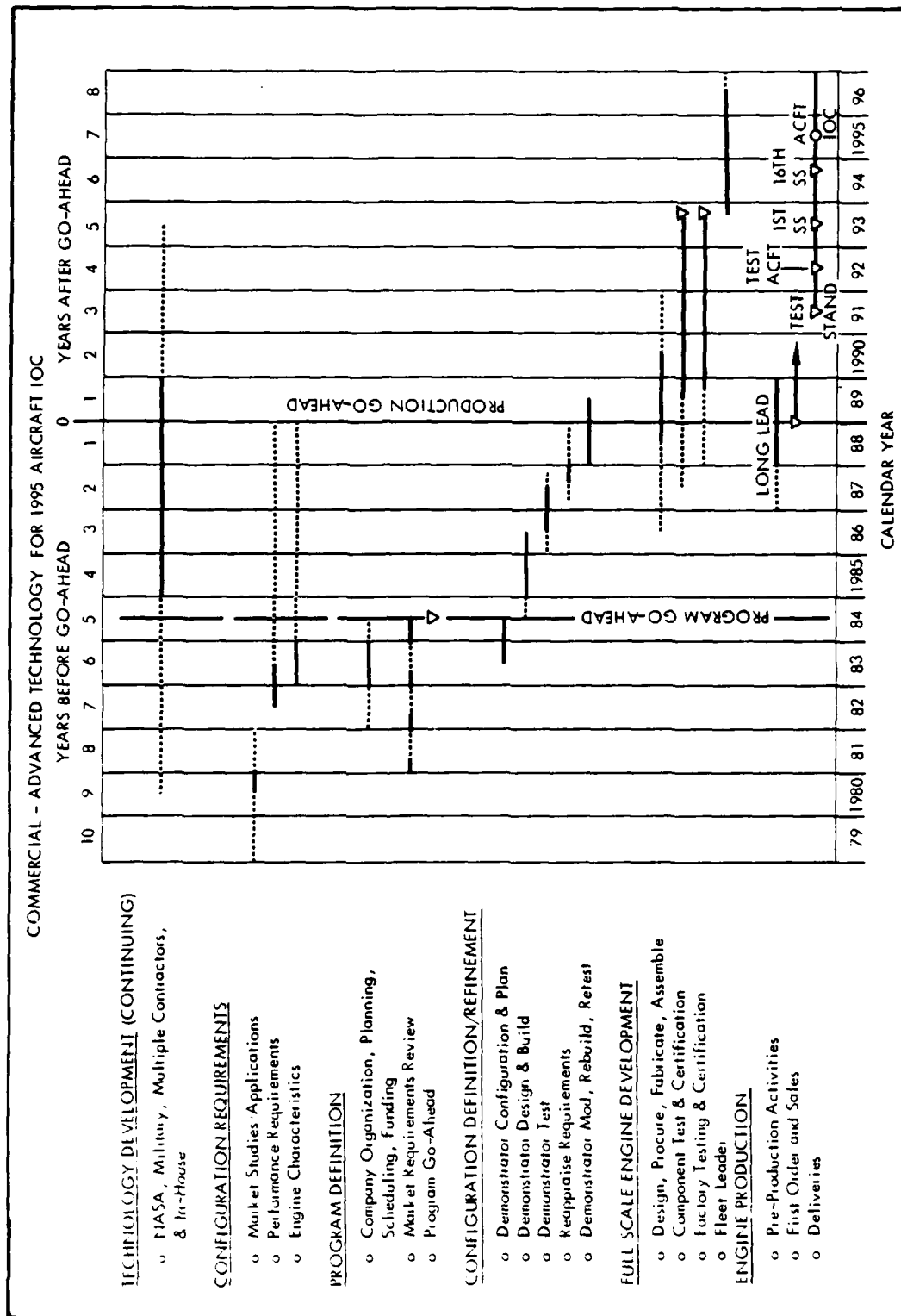


Figure 46. Representative Transport Engine Development (Commercial)

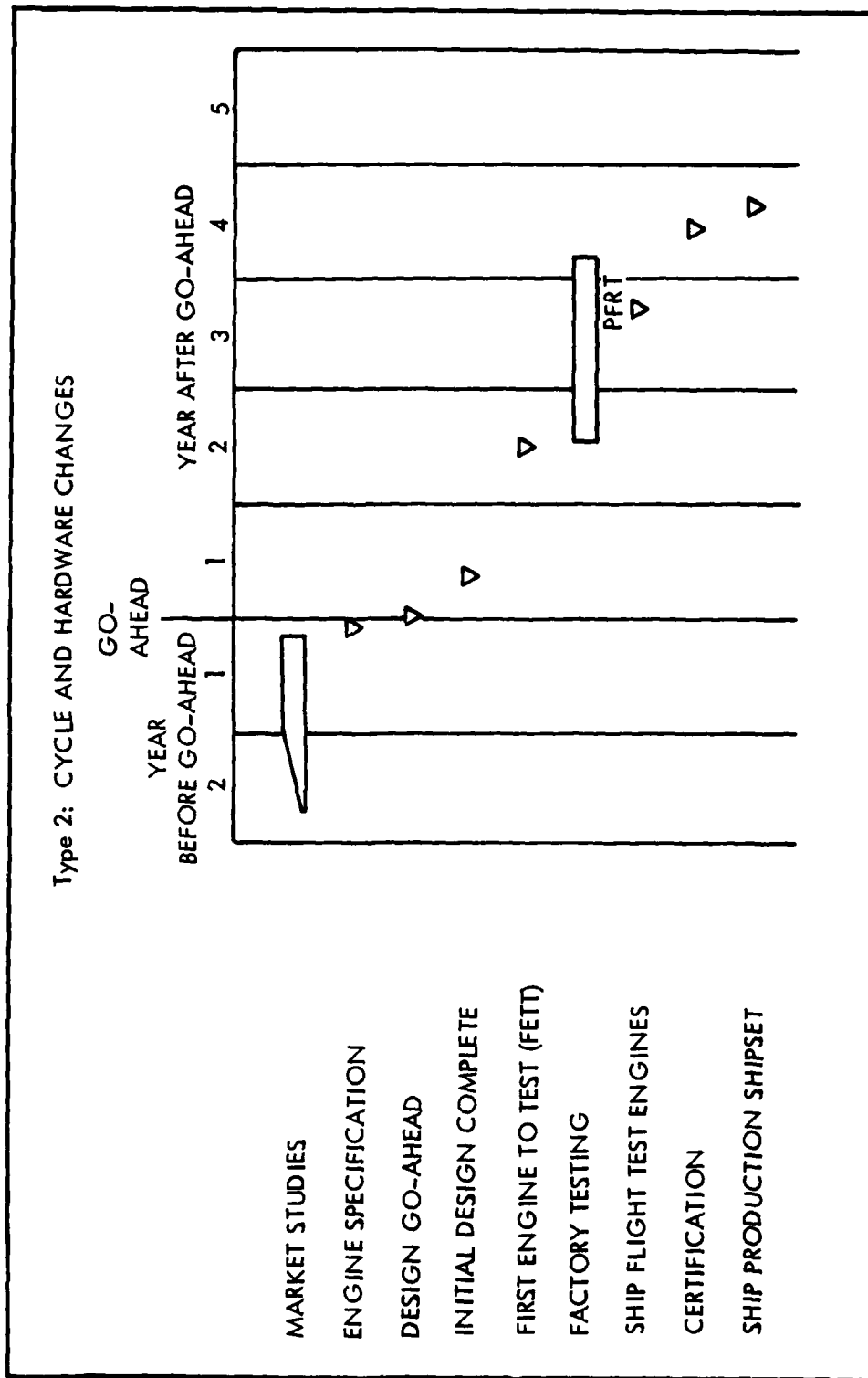


Figure 47. Representative Derivative Engine Program

Key Milestones

Based on these schedules, the following are key milestones to support a 1995 IOC for the ACMA:

| <u>AIRCRAFT MILESTONES</u> | <u>Date</u> |
|--|-------------|
| o Start of configuration studies to respond to defined requirements | Oct 1982 |
| o Definition of specific configuration (or configurations for competitive studies) | Mar 1985 |
| o Issue system performance specification | Nov 1986 |
| o Start design and development of test vehicle and/or production configuration | Oct 1987 |
| o First flight of test vehicle | Jan 1991 |
| o First delivery of customer training aircraft | Jan 1994 |
| o Aircraft certification and production delivery | Jul 1994 |
| o Delivery of 16th aircraft (IOC) | Jul 1995 |

RELATED ENGINE AND POWERPLANT MILESTONES

| | |
|---|----------|
| o Start specific engine studies to support specific aircraft studies | Jan 1984 |
| o Issue preliminary engine specification (and propeller, if applicable) | Apr 1985 |
| o Issue final engine specification. | Dec 1985 |
| o Start design and development of engine (and propeller) | Jan 1986 |
| o Delivery of first engines for flight test aircraft (and propeller) | Apr 1990 |
| o Certification of production configuration | Jul 1993 |
| o Delivery of first production shipset | Jul 1993 |
| o Delivery of 16th production shipset | Jan 1995 |

VI. SUMMARY OF OBSERVATIONS AND RECOMMENDATIONS

In the course of the study, we found that the need for improvements in civilian and military air transportation efficiency and flexibility has been recognized by responsible officials in both government and industry. Motivated primarily by economic considerations, the ACMA development concept as examined in this study offers both the commercial carriers and the military sufficient incentive for initiating a formal cooperative airlift development effort. And although diverse procedural, operational, and financial practices pose an immediate obstacle, they are not viewed as insurmountable given the ultimate benefits of such a cooperative venture. Likewise, the engine and energy issues are not seen as detrimental to the initiation or completion of the program.

For the military, the commonality concept offers an answer to the growing concern over the capabilities of U.S. airlift forces to effectively and rapidly respond to developing contingencies in areas of national interest anywhere in the world. And for commercial cargo carriers, faced with an uncertain cargo market and limited means to stimulate it themselves, a joint civil/military venture would be a highly attractive course for enhancing their domestic/international airfreight capabilities.

In general terms then, based upon the four issue areas covered in this study, we found no serious impediments to a cooperative civil/military airlift development effort. There are, however, several problem areas which will require further investigation as a basis for a more in-depth understanding of a proposed cooperative program. Our specific summary observations for the four issue areas covered in this study follow.

THE COMMERCIAL NEED

We found a considerable base of support within the airline industry for the concept of a joint civil/military airlift development program. There are, however, differing views on the size and capabilities of the aircraft needed.

Among the contacts we made, the feeling is that the success of such a cooperative venture will be heavily dependent upon the degree to which the commercial carriers are allowed to participate.

Our examination of the various cargo market forecasts available did not provide us with the necessary data for establishing the potential size of the civil market for a new advanced technology cargo aircraft. There was, however, general agreement among those we consulted that there is a commercial need for a new cargo aircraft to satisfy the projected growth in the air cargo market in the late 1990-2010 time period. The big question remains the ultimate size of the U.S. and foreign market. Since the driving force for the initiation of such a program is the emergency defense airlift requirements, there is a strong consensus that the government must provide all "front-end" financing.

FINANCIAL PLAN

General

The dynamics of the current socio-political forces, coupled with the increasing competition among Federal agencies for major funds, has focused attention on the necessity for increasing dependence upon civilian airlift capabilities in order to meet national defense airlift needs. But, as we have noted, there is substantial evidence supporting the growing commercial need for a new large cargo airplane which, with expected improvements in system economics, can further stimulate the air cargo market.

Government Financing

The magnitude of the development task and the near-term financial situation of the U.S. aviation industry precludes launching this program solely as a private venture. In view of the necessity for federal participation in the program, the provisions of OMB Circular A-109 will apply.

Since the primary motivation for pursuing a cooperative development concept is based on a fundamental requirement to provide augmentation to our outsize emergency airlift capability, we foresee that all funding for the conceptual

and validation phases would be provided by the government. Assuming the final design configuration is tailored to meet the demands of the air cargo market, we anticipate that government and industry would share the cost of the full-scale engineering development phase. The formula for joint participation will be considered at an appropriate time during the conceptual phase.

During the production phase Federally funded R&D costs would be recouped for commercial production aircraft, and at the time of go-ahead the R&D costs would be added to the planned production program on a pro rata basis. When the planned program is accomplished, Federal funds would be recovered on a ratio of commercial to total production. In the event the planned program production is exceeded, the government would recoup a greater percentage of funds with the potential of eventually making a profit. The rates of recoupment per unit production after the initially planned program production would be subject to negotiation and the overall economic conditions of the competitive market. If the initially planned production was not accomplished, the government recoupment would be less. The risk associated with the different outcomes would be analyzed before go-ahead.

Private Financing

Consultations with the many senior representatives of the major carriers and the senior Lockheed Corporation financial staff provide the basis for the findings summarized below:

- o Significant contributions from private industry are appropriate and obtainable.
- o Commercial financing is available to air carriers for the purchase of large cargo aircraft that can be operated profitably.
- o Potential improvements in system economics will avoid the need for government guaranteed low interest/no interest loans or subsidies to carriers for purchase of the aircraft.
- o Development of a system with significant competitive advantages in terms of DOC and energy efficiency could be highly attractive to both U.S. and foreign operators/investors and could reduce the level of federal funds required for program success.

- o Initial industry funding during the validation phase will provide a gauge of commercial interest. Cost sharing may be the best means to gauge industry's faith in the proposed program objectives and also be the most convincing in selling the program to Congress and the public.
- o Commercial financial participation may be directly related to the degree of influence exercised by commercial interests during the system definition phase.
- o Industry's share of additional development and program costs is to be based on further study of the risks involved.

International Participation

We believe the concept of a joint government industry program for the development of an advanced technology all-cargo aircraft system will be attractive to international carriers. An initial summary of findings pertaining to potential international participation is shown below:

- o An advanced technology ACMA with superior commercial economics can be expected to be attractive to international carriers.
- o Potential international sales could represent up to two-thirds of total market.
- o Offset will be a major consideration in international sales.
- o Joint venture between United States and foreign countries could involve both manufacturing and investment capital.
- o International carriers can be expected to obtain financing from private in-country sources.

ENERGY ISSUE

When we began this investigation of the energy issue we responded to the question: "Will it be in the public interest to develop a new air cargo transportation system for the 1990s in view of increasing fuel prices and diminishing domestic supplies?" We now feel that the answer to that question must be "Yes." Fuel costs are occupying a larger and larger part of direct operating costs. If air cargo is to continue to operate profitably, it must carry more cargo on less fuel. Certainly from an energy standpoint alone, any aircraft that could accomplish the same mission on substantially less fuel would be an attractive investment to any air cargo operator.

There are many energy-conservation options that may be incorporated into the design of the next airlifter. This does not mean however that the ACMA should be designed for optimum energy efficiency. In the final analysis, total economics will govern the design of the 1990s civil/military airlifter.

ENGINE ISSUE

Propulsion Technology

Required propulsion technology is dependent on the required aircraft capability which, in turn, is dependent on the aircraft technology level.

- o High aircraft L/D reduces thrust required and can permit acquisition of derivatives of current engines that might still be in production in the late 1980s and early 1990s.
- o Derivative engines will not have as favorable weight or sfc characteristics as advanced technology engines. The result would be a heavier aircraft that is more costly in fuel consumed for a selected payload and range.

Engine Type

The engine type and required technology level will establish development program timing and determine whether or not propulsion is likely to pace the program.

- o Use of derivatives of a current engine should pose no program scheduling problem.
- o Use of next generation technology - the Energy Efficient Engine (E^3), or a derivative of it, should pose no problem if hardware requirements are identified upon completion of the scheduled integrated core/low spool tests in 1983, and hardware development is under way by 1987.

Potential Propulsion Program Pacing

Technology beyond the E^3 level has been identified but is presently not being actively supported. NASA is not likely to leapfrog E^3 with further advanced

technology until the E³ is successful in meeting its objectives. Initial indications of this should be available in 1982 with full engine results in 1983.

If the E³ technology level is selected for early-1980s aircraft validation studies; if the required engine thrust level is acceptable to the engine manufacturers; and if engine full-scale development is committed by 1987, prototype engines should be available for first flight in 1991.

If full scale engine development were not committed in 1987, other engines would be required for initial flight testing in 1991, and availability of E³ technology level engines would depend on when the engine program go-ahead occurred.

A large advanced technology propeller for a common transport, and its gearbox and engine, could be available with the NASA technology program accelerated, and with a specific selection by 1986. The turboprop powerplant could be available for the aircraft without significantly greater schedule risk than from a comparable turbofan.

RECOMMENDATIONS

We have identified the following tasks as logical extensions of the work accomplished during this study. Although centered around the need for the development of a mutually acceptable financial planning concept, a more in-depth investigation of all these interdependent issues (Figure 48) is considered critical to the future success of the commonality concept.

The order in which these tasks are listed does not represent their relative importance or priority.

- o Economic/Market Studies
 - Validation of both U.S. and international civil needs through an analysis of both the size and timing of the world-wide market requirements for a new large advanced technology cargo aircraft

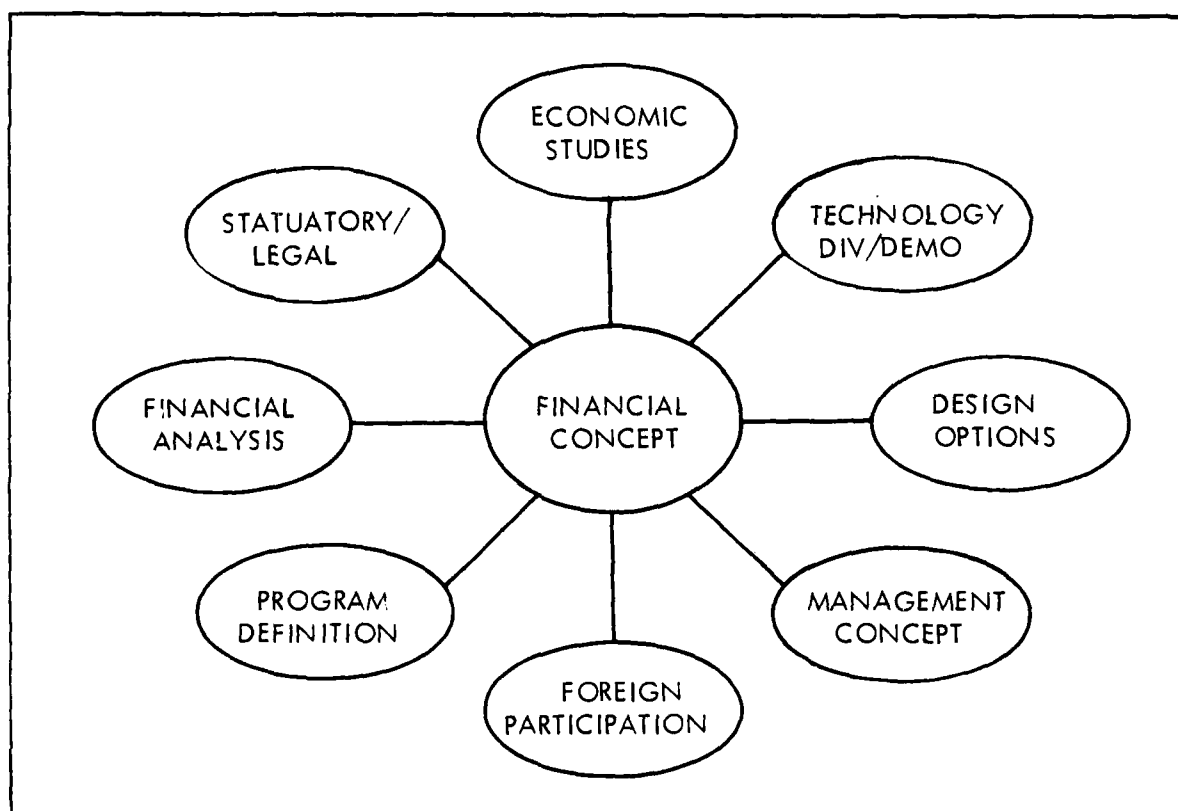


Figure 48. Recommendations

- o Management Concepts - Establishment of the basis for government and private sector cooperative management decisions--from the highest policy levels through detailed program management

- o International Participation - Evaluation of potential implications of NATO and other free-world countries' participation in the program, either as active participants or as potential operators. Possible joint ventures and offset implications should be evaluated.

- o Financial Analysis - Identification of the effects of program variables, such as market potential, aircraft cost, life-cycle costs, and operational benefits for both civil and military operators

- o Statutory/Legal - Draft enabling legislation to establish among other things: national priority; authorizations; roles and responsibilities of all parties; financial arrangements, concepts and provisions for international participation and program monitoring; evaluations of potential regulatory and anti-trust implications; and recommended solution paths

We also recommend that parallel design options studies be continued in order to establish essential preliminary system specifications and potential system economic data as a base for a more in-depth exploration of the many complex issues inherent in the program.

Finally, we recommend that cooperative technology developments directed specifically toward very large aircraft applications be pursued either separately or jointly by NASA and the Air Force. Appropriate technology demonstrations should be planned in such a manner that the necessary confidence level is established in time for incorporation of the results into the detailed design phase of the program.

APPENDIX

OVERVIEW OF PHASE I, ISSUES OF COMMONALITY STUDY

The Innovative Aircraft Design studies beginning in 1976 (Reference 2) demonstrated the technical feasibility of the AQMA (nee C-XX) concept. Many institutional issues, ancillary to the technical aircraft design, yet critical to the successful implementation of a joint program still required assessment, however. Accordingly, the Aeronautical Systems Division (ADS/XRL) sponsored a study to address such non-technical issues as commercial and military system acquisition policies and procedures; commercial market forecasts; and future energy considerations.

This "Issues of Commonality Study" was divided into two distinct phases. The following is a brief overview of the Phase I focused on the preliminary identification of significant institutional issues and the preparation of initial background descriptions and fundamental causes. Once we had developed the preliminary listing of potential issues, they were reviewed by commercial air carrier representatives and personnel from MAC, NASA, AFSC/ASD, and other government agencies. Their comments and advice enabled us to obtain a realistic cross-section of viewpoints regarding significant issues.

The results of this initial identification effort were then expanded, and individual "Issue Reports" were prepared on each which included a definition of the issue, its background, the positions of principal parties, and a general outline of events necessary to resolve the issue. A prioritized listing of these issues, shown in Table 12 was then compiled based on our subjective review of each. Number 1 is the "most critical" issue, and Number 16, the "least critical."

These 16 "Issue Reports" were then submitted as an Interim Report to the ASD Project Engineer who subsequently selected six issues for further investigation. Following his suggestion, we combined these six into the four issues addressed in depth in this "Issues of Commonality Study" final report.

TABLE 12
ISSUE LISTING

1. How will action be initiated to establish a valid basis for documenting and processing the combined civil/military needs.
2. Should an existing federal organization be designated to organize/ manage the program, or should a new organization be established.
3. How to present the program to the Congress and the White House.
4. Establishment of the commercial need.
5. Timing of the program initiation considering possible existing aircraft modifications/derivatives.
6. How to develop mutually-acceptable commercial/military aircraft specification requirements.
7. The development of a financial planning concept for the development, acquisition, and operation of the system including the basis for re-coupment of federally funded R&D cost.
8. How to compensate airlines for a compromised aircraft that reduces profits.
9. Environmental considerations that may impact the program.
10. Energy considerations that may impact the program.
11. How to determine whether the joint civil/military aircraft is a single model or a family of aircraft.
12. International commercial sales.
13. What type of procurement process should be used.
14. Is the engine development/acquisition program a pacing factor.
15. Are changes needed in CRAF procedures to assure dependable response capability for aircraft call-up.
16. What process will be used for the joint airline/military design decisions and control of design changes.

GLOSSARY OF TERMS

ACQUISITION - the process consisting of planning, designing, producing and distributing a weapon system/equipment.

ACQUISITION PROGRAM - a defined effort funded by RDT&E and/or procurement appropriations with the express objective of providing a new or improved capability in response to a stated mission need or deficiency.

AROMATICS - Hydrocarbon compounds containing benzene.

CONCEPT FORMULATION - the activities preceding a decision to carry out Engineering Development.

CONCEPTUAL PHASE - the initial period when technical, military and economic bases for acquisition programs are established through comprehensive studies and experimental hardware development and evaluation, resulting in alternative concepts and their characteristics.

CONVENTIONAL FUEL - kerosene and naptha-based fuels which are refined from petroleum.

COMPOSITE STRUCTURES - structures made from graphite/epoxy, baron/aluminum, glass fiber/epoxy and other lightweight, very strong matrix materials.

CRYOGENIC - a substance that exists in liquid form only at very low temperatures.

DEMONSTRATION AND VALIDATION PHASE - the period when selected candidate solutions are refined through extensive study and analyses, hardware development as appropriate, test, and evaluations.

DEVELOPMENT TEST AND EVALUATION (DT&E) - the T&E conducted to demonstrate that the engineering design and development process is complete and that the design risks have been minimized, that the system will meet specifications and that estimate the system's military utility when introduced to operating units.

GLOSSARY OF TERMS (Cont'd)

E³ - Energy Efficient Engine project being conducted by NASA with participation from General Electric and Pratt and Whitney.

ENGINEERING DEVELOPMENT - includes those development programs being engineered for service use but which have not yet been approved for procurement or operation.

EXPLORATORY DEVELOPMENT - includes all effort toward the solution of specific military problems, short of major development projects.

FULL-SCALE ENGINEERING DEVELOPMENT PHASE (FSED) - the period when the system and the principal items necessary for its support are designed, fabricated, tested, and evaluated.

HYDROCARBONS - organic compounds composed of hydrogen and carbon.

HYDROGENATION - the process of adding hydrogen to hydrocarbon molecules to alter the properties of a given compound of substance.

INITIAL OPERATIONAL CAPABILITY (IOC) - the first attainment of the capability to employ effectively a production item or system.

INITIAL OPERATIONAL TEST AND EVALUATION (IOT&E) - that T&E performed during a development program intended for acquisition.

MIDDLE DISTILLATES - petroleum products obtained from the middle of a fractional distillation.

MISSION ELEMENT NEED STATEMENT (MENS) - a statement prepared by a DoD component to identify and support the need for a new or improved mission capability. The mission need may be the result of a projected deficiency or obsolescence in existing systems, a technological opportunity or an opportunity to reduce operating costs. The MENS is submitted to the SECDEF for a Milestone 0 decision.

GLOSSARY OF TERMS (Cont'd)

OIL SHALE - certain mineral deposits containing an organic substance called "kerogen" which is chemically similar to petroleum.

OPERATING COMMAND - the command or agency primarily responsible for the operational employment of a system, subsystem or item of equipment.

PRODUCTION PHASE - when operational equipment and the principal items necessary for its support are procured in quantity.

RECOUPMENT - estimated cost savings from prior year programs used to finance current programs.

REFINERY FEEDSTOCK - oil that is ready to be processed by a refinery into its various end products.

REQUIREMENTS REVIEW GROUP (RRG) - a HQ USAF general officer review board which reviews, evaluates, and recommends on proposals for new or improved operational capabilities submitted through channels established. (Air Force)

STATEMENT OF OPERATIONAL NEED - a document used to identify an operational deficiency and state the need for a new or improved capability for USAF forces.

SPECIFIC FUEL CONSUMPTION (SFC) - a means of quantifying the fuel efficiency of an engine expressed as pounds of fuel per hour per pound of thrust.

STRATEGIC AIRLIFT - oversize and outsize-capable, long-range military cargo aircraft.

SYNTHETICS - fuels with properties similar to conventional fuel but produced from sources other than petroleum.

TAR SANDS - hydrocarbon deposits of sand containing large amounts of tar (bitumen) located principally in Canada.

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